NASA CR-66512
(NSL 67-300)

ORBITING EXPERIMENT FOR STUDY OF EXTENDED WEIGHTLESSNESS

Volume VI

ORBITING PRIMATE SPACECRAFT APPLICATIONS

Prepared under Contract No. NAS1-6971 by
NORTHROP SYSTEMS LABORATORIES
Hawthorne, California
for
Langley Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT

This document constitutes a portion of the final report under contract NAS 1-6971, Orbiting Experiment for study of Extended Weightlessness, for the Langley Research Center, National Aeronautics and Space Administration, Hampton, Virginia. The following 6 documents comprise the total report:

NASA CR-66507	Volume I	Summary
NASA CR-66508	Volume II	System Definition
NASA CR-66509	Volume III	Spacecraft Preliminary Design
NASA CR-66510	Volume IV	Laboratory Test Model
NASA CR-66511	Volume V	Program Plans
NASA CR-66512	Volume VI	Orbiting Primate Spacecraft Applications

This report summarizes the results of a definition study of a spacecraft system to support two primates in unattended, weightless, earth-orbital flight for extended periods of time. The experiment is planned as part of the Apollo Applications Program; the spacecraft launched as a LEM substitute on an AAP flight; the primates recovered by Astronaut EVA on a later flight and returned to earth in retrieval canisters within the Command Module. Intensive post-flight examination is planned to ascertain even subtle physiological changes in the primates due to their extended exposure to weightlessness. The study includes definition of mission profile and Apollo Applications Program interfaces, preliminary design of the spacecraft, and planning for subsequent phases of the program.

CONTENTS

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ILLUSTRATIONS

TABLES

LIST OF ABBREVIATIONS

A	Analog
AAP	Apollo Applications Program
ACE	Automatic Checkout Equipment
ACM	Apollo Command Module
ACS	Attitude Control System
A/D	Analog to Digital
AFB	Air Force Base
AGC	Automatic Gain Control
Ag-Zn	Silver-Zinc
APC	Automatic Phase Control
APIC	Apollo Parts Information Center
AM	Airlock Module
ASME	American Society for Mechanical Engineers
ASPR	Armed Services Procurement Regulation
ATM	Apollo Telescope Mount
AVD	Avoidance Component
B	Biological
BCD	Binary Coded Decimal
BLO	Phase Lock Loop Bandwidth of Ground Receiver
BPM	Beats Per Minute
BW	Bandwidth
C	Control (Present)
C&C	Command and Control
CCW	Counter-Clockwise
C/D	Count Down

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CDR	Critical Design Review
CEI	Contract End Item
CG	Center of Gravity
CIBA	CIBA Parmaceutical Company
C_L	Centerline
CM	Command Module
Cmds	Commands
C/O	Checkout
CO_2	Carbon Dioxide
CONFAC	Configuration Factor Computer Program
CRB	Configuration Review Board
CSM	Command Service Module
CW	Clockwise
D	Degradation
DAF	Data Acquisition Facilities
DB	Decibel
DCASR	Defense Contract Administrative Service Region Agent
DFO	Director of Flight Operations
DMU	Dual Maneuvering Unit
DOD	Department of Defense
DR	Discrepancy Report
DRD	Document Requirement Description
DRL	Data Requirements List
DRR	Document Request and Release
DSIF	Deep Space Instrumentation Facilities
E	Engineering
E	Event

ECG	Electrocardiogram
ECP	Engineering Change Proposal
ECS	Environmental Control System
ECU	Environmental Control Unit
EDS	Experiment Data System
EKG	Electrocardiogram
EO	Engineering Order
EMI	Electromagnetic Interference
ETR	Eastern Test Range
EVA	Extravehicular Activity
EXC	Exercise Component
FAB	Fabrication
FACI	First Article Configuration Inspection
FARADA	Failure Rate Data Program
FC-75	Minnesota Mining & Manufacturing (Product Designator)
FM	Frequency Modulated
FMEA	Failure Mode, Effect, and Analysis
FMECA	Failure Mode, Effect, and Criticality Analysis
FOV	Field-of-View
FSC	Flight Spacecraft
FTM	Functional Test Model
GAEC	Grumman Aircraft Engineering Corporation
G&C	Guidance and Control
GCPY	Gas Consumed Per Year
Gen.	Generator
GETS	Ground Equipment Test Set

GFE	Government Furnished Equipment
Gnd	Ground
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
h	Unit of Hysteresis
Hg	Mercury
Hz	Hertz
ICD	Interface Control Document
I.D.	Inside Diameter
IDD	Interface Definition Document
IDEP	Interservice Data Exchange Program
ILK	Interlock Task
I/O	Input/Output
IR	Infrared
IU	Instrument Unit
KC	Kilocycles
Kg	Kilogram
KSC	Kennedy Space Center
LEM	Lunar Excursion Module
LES	Launch Escape System
LiOH	Lithium Hydroxide
LM	Lunar Module
LMS	Lunar Mapping System
LMSS	Lunar Mapping and Survey System
LOS	Line-of-Sight
LRC	Langley Research Center

LSS	Life Support System
LTM	Laboratory Test Model
LUT	Launch Umbilical Tower
LV	Launch Vehicle
M	Mission
MAA	Maintenance Assembly Area
MAAS	Manufacturing Assembly and Acceptance Sheet
MC	Control Moment
MCC-H	Mission Control Center - Houston
MCP	Management Control Plan
MDA	Multiple Docking Adapter
MEI	Master End Item
MFOD	Manned Flight Operations Division
MHz	MegaHertz
MLF	Mobile Launch Facility
M&O	Mission and Operations
MOL	Manned Orbiting Laboratory
MRB	Materials Review Board
MS	Multiple Schedule
MSC	Manned Spacecraft Center
MSF	Manned Space Flight
MSFC	Marshall Space Flight Center
MSFN	Manned Space Flight Network
MSOB	Manned Spacecraft Operation Building
M/VM	Mass/Volume Measurement
M/V MD	Mass/Volume Measurement Device

N	Nuisance
NA	Not Applicable
NAA	North American Aviation, Inc.
NAMI	Naval Aerospace Medical Institute
NASCOM	NASA Communications Division
NASCOP	NASA Communications Operating Procedures
NRZC	Non-Return to Zero Change
NSL	Northrop Systems Laboratories
OCP	Operational Checkout Procedures
O.D.	Outside Diameter
OMSF	Office of Manned Spaceflight
OPS	Orbiting Primate Spacecraft
P	Performance (past)
PAM	Pulse Amplitude Modulation
PCM	Pulse Code Modulation
PCU	Pyrotechnic Control Unit
PDR	Preliminary Design Review
PERT	Program Evaluation Review Techniques
PI	Principal Investigation
PIA	Preinstallation Acceptance (test)
PLSS	Portable Life Support System
PM	Phase Modulation
PPM	Parts Per Million
PRINCE	Parts Reliability Information Center
PSC	Primate Spacecraft
PWR	Power
Q	Quick look

QA	Quality Assurance
QC	Quality Control
QM	Qualification Model
QTM	Qualification Test Model
R	Redundant feature
Rad	Irradiation dose unit of measurement
Rad.	Radius
RCS	Reaction Control System
RF	Radio Frequency
RH	Relative Humidity
RMS	Root Mean Square
RTG	Radioisotope Thermoelectric Generator
S	Saftey
SAA	Saturn Apollo Applications
S/AAP	Saturn Apollo Applications Program
S/C	Spacecraft
SCD	Specification Control Drawing
SCN	Specification Change Notice
Seq	Sequence
SGL	Space Ground Link
SIB	Saturn IB
SLA	Spacecraft LEM Adapter
SM	Service Module
SNR	Signal to Noise Ratio
SPS	Service Propulsion System
SRO	Superintendent of Range Operations
STADAN	Space Tracking and Data Acquisition Network

STM	Structural Test Model
TCM	Thermal Control Model
TCS	Thermal Control Subsystem
TE	Time Estimation
TIG	Tungsten Inert Gas
TIM	Timing Task
TLM	Telemeter
TM	Thermal Model
TTM	Thermal Test Model
TWT	Traveling Wave Tube
UCLA	University of California at Los Angeles
USC	University of Southern California
UV	Ultraviolet
VAB	Vertical Assembly Building
VCO	Voltage Controlled Oscillator
VIG	Vigilance Task
VOM	Volt-Ohmmeter
WMS	Waste Management System
WMU	Waste Management Unit
WTR	Western Test Range

INTRODUCTION

The design of the Orbiting Primate Spacecraft provides the type of services and thermal control that would be required by many orbital experiments. These services include attitude control, power, data handling, environmental control and thermal control. In order to determine the versatility of this design to perform additional applications, a number of possible experiments were examined in some detail. The selection of the experiments examined was not intended as a recommendation or evaluation of scientific merit but as a means for making a realistic assessment of the effect of other experiment requirements on the spacecraft design.

Areas examined in detail for extended use were:

(1) Performance of additional experiments together with the prime experiment of two primates in unattended, extended duration, zero gravity earth orbit.

(2) Performance of other biological experiments in place of the prime experiments of two primates in unattended, extended duration, zero gravity earth orbit.

(3) Application of the primate spacecraft or its systems in connection with an orbiting laboratory.

The study revealed the Orbiting Primate Spacecraft has considerable potential, as an orbiting bus, for accepting and supporting a broad spectrum of experiments ranging from engineering development tests of future hardware designs to scientific experiments in the physical, planetary, and life sciences disciplines.

Orbiting Primate Spacecraft Description

The Orbiting Primate Spacecraft is a functionally integrated unit designed for use in the SAA program as an LEM companion or LEM substitute payload on manned or unmanned vehicles with a self sustaining capability of six months to one year.

External configuration. - As shown in figures 1 and 2, the spacecraft, which will weigh approximately 5,000 pounds, consists of a pressurized cylindrical upper section joined to an unpressurized octagonal lower section. The sides and top of the cylinder form one removable unit, flange mounted at a sealed joint to the bulkhead to form the bottom of the cylindrical section of the spacecraft. The octagonal lower section contains most of the subsystem equipment. The flat panels forming the sides of the octagonal structure serves as bases and heat sinks for electronic equipment mounted to interior surfaces. A 20 by 20 inch sealable door provides access to the pressurized area for inserting the primate or maintenance of the life cell. Meteoroid shielding panels backed with thermal insulation are attached to the external structural stringers. In addition, the thermal control subsystem radiator is mounted to the external vertical stringer and covers an area of the cylindrical section approximately eleven inches in width and extends completely around the circumference; thereby supplementing the meteoroid shielding and insulation in this region.

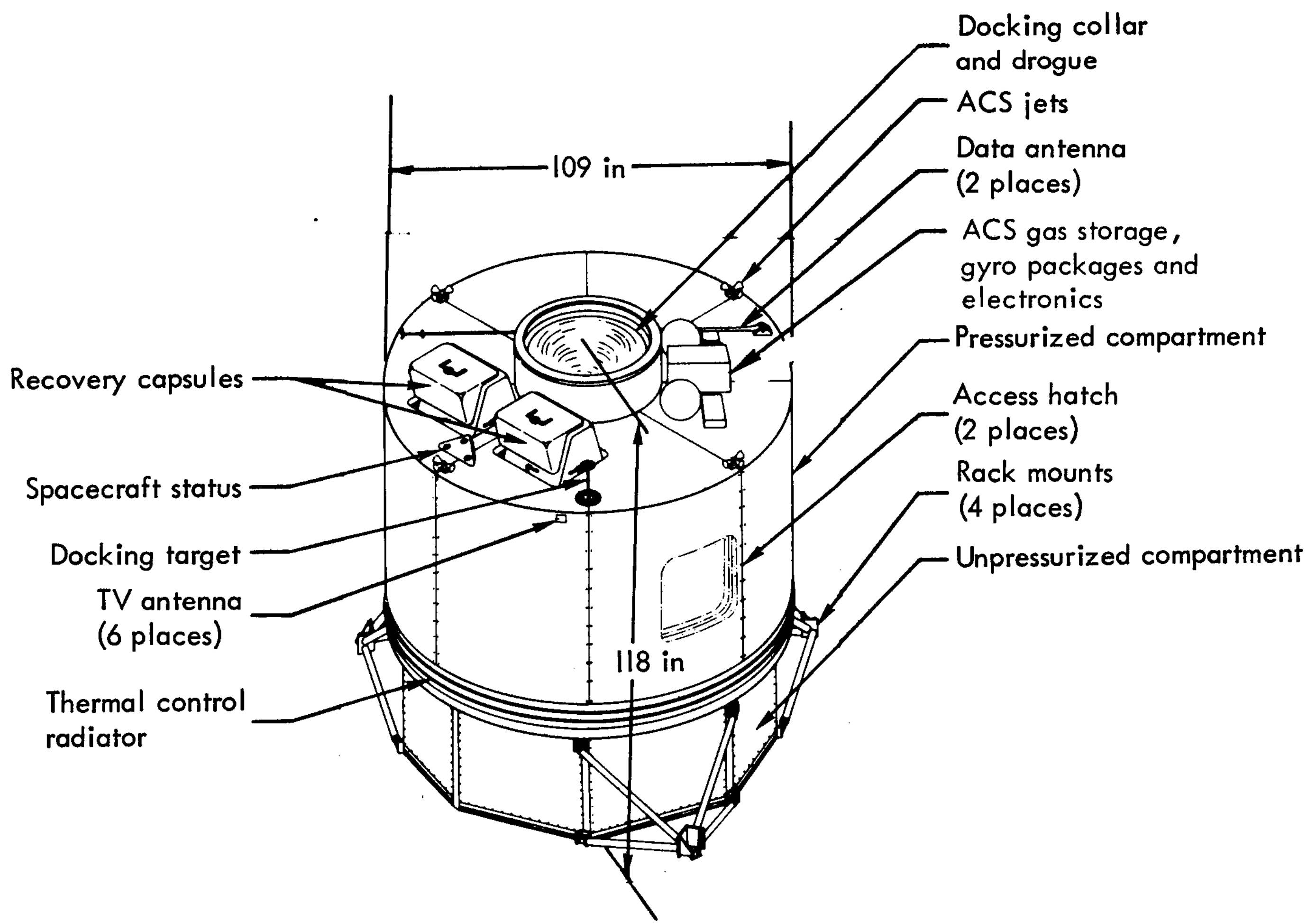

Figure 1. - Spacecraft configuration in stowed position

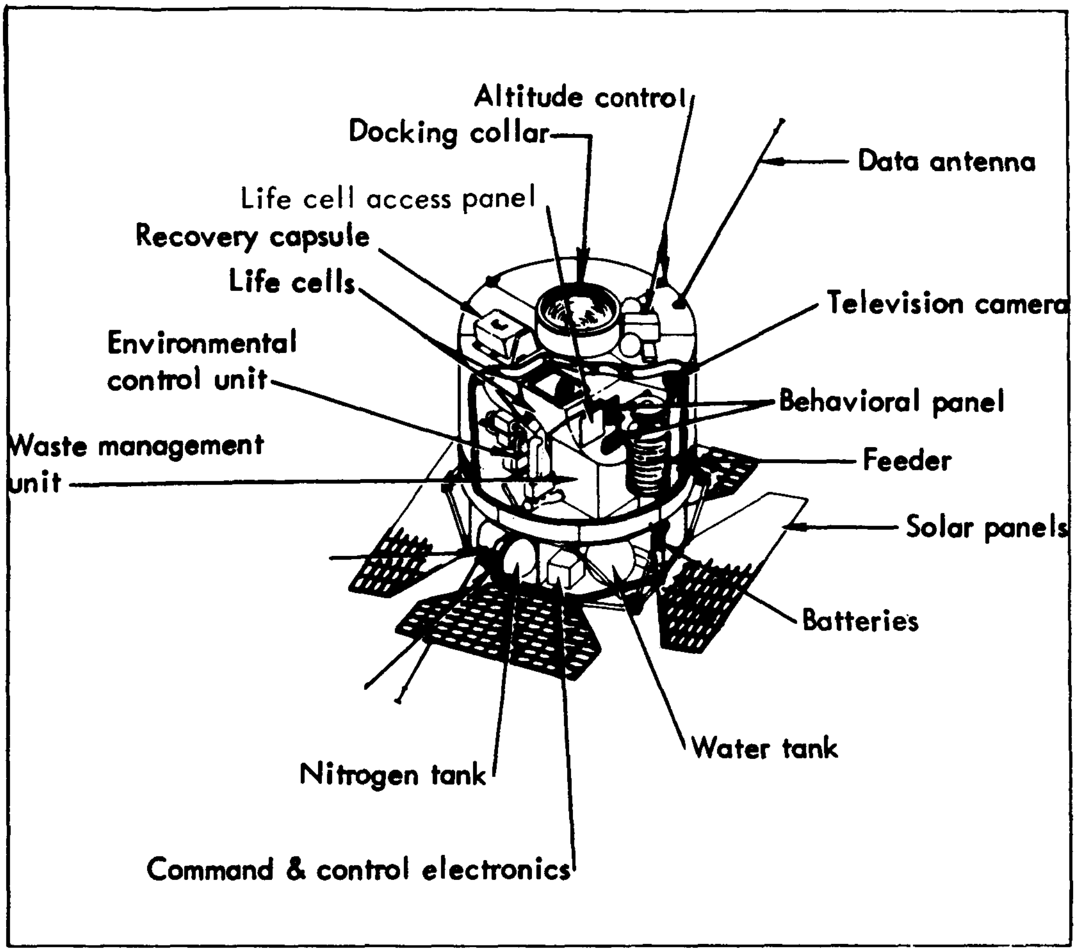

Figure 2. - Spacecraft configuration in deployed position

Four tubular truss assemblies are utilized to mount the spacecraft to the ATM, LMSS or other appropriate structures in the SLA area of the Apollo Launch Vehicle. These attach points are separated pyrotechnically following docking of the spacecraft and command module. To facilitate docking, a docking collar, located on the upper bulkhead of the spacecraft, contains an LEM type drogue which engages with the command module probe during the docking operations. The primate recovery capsule is also mounted on the upper bulkhead to facilitate removal during extra vehicular activities. In this position, the capsule can be easily reached by the astronaut standing in an open hatch in the command module. In addition, a visual docking aid for use during the docking maneuver and the spacecraft status monitoring panel are visible on the upper bulkhead from the command module window.

Five flush-mounted television antennas, four mounted 90° apart around the periphery and one of which is mounted on the top bulkhead are located on the top section of the spacecraft. A boom mounted and deployable communications antenna is also located on the upper bulkhead. The deployed antenna is positioned to eliminate any interference between the spacecraft and the command module during docking. In addition, a television antenna and a communications antenna are mounted at the bottom end of the spacecraft.

The octagonal shaped end of the spacecraft mounts the four paddles which form the solar array. As shown in figure 1, the array panels fold over against the bottom spacecraft surface in the stowed position with their shape conforming with the octagonal outline of the bulkhead to facilitate stowage. Figure 2 depicts the solar array in the deployed condition with the active area facing away from the spacecraft. Two more antennas are mounted at the end of the spacecraft - - an additional television antenna, centrally located on the bottom surface, and a communication antenna similar to the one mounted at the opposite end.

Internal configuration. - Two major internal areas comprise the interior of the spacecraft as shown in figure 2: The pressurized volume within the cylindrical section and the unpressurized octagonal section below which contains most of the support subsystems.

The pressurized portion of the spacecraft contains two life cells to accommodate the primates. The two life cells are located side by side with approximately one inch of space between them. The major equipment attached externally to the life cells include: television cameras, waste devices. The environmental control equipment is also mounted within the pressurized section and interfaces directly with the waste management assembly. The following major units of environmental control equipment are located in the pressurized area: air filters, condensers, evaporation, primary and secondary fans, and a catalytic burner.

Electronic subsystems elements as well as the expendables other than food, which are stored in the Feeder, are located in the unpressurized, lower octagonal section of the spacecraft. The environmental control equipment located in this area consists primarily of: nitrogen and oxygen cryogenic storage tanks, heat exchanger between primary and secondary thermal loops, coolant pump, accumulator, control module, gas analyzer, and lithium hydroxide. The location of the lithium hydroxide unit is also influenced by its need for a thermal input which can best be obtained through the spacecraft surface facing the sun. Therefore, the lower end of the lithium hydroxide container forms part of the solar oriented, bottom surface of the spacecraft.

Subsystem Summary

The subsystems which comprise the spacecraft have been broken down into the following functional areas:

(1) Life Support

(2) Thermal Control

(3) Structure and Mechanical

(4) Instrumentation

(5) Telemetry

(6) Command and Control

(7) Electric Power and Cabling

(8) Attitude Control

Detailed descriptions of these subsystems are presented in Volume III of this report. An overall system block diagram indicating the functional equipment and interfaces between subsystems is shown in figure 3.

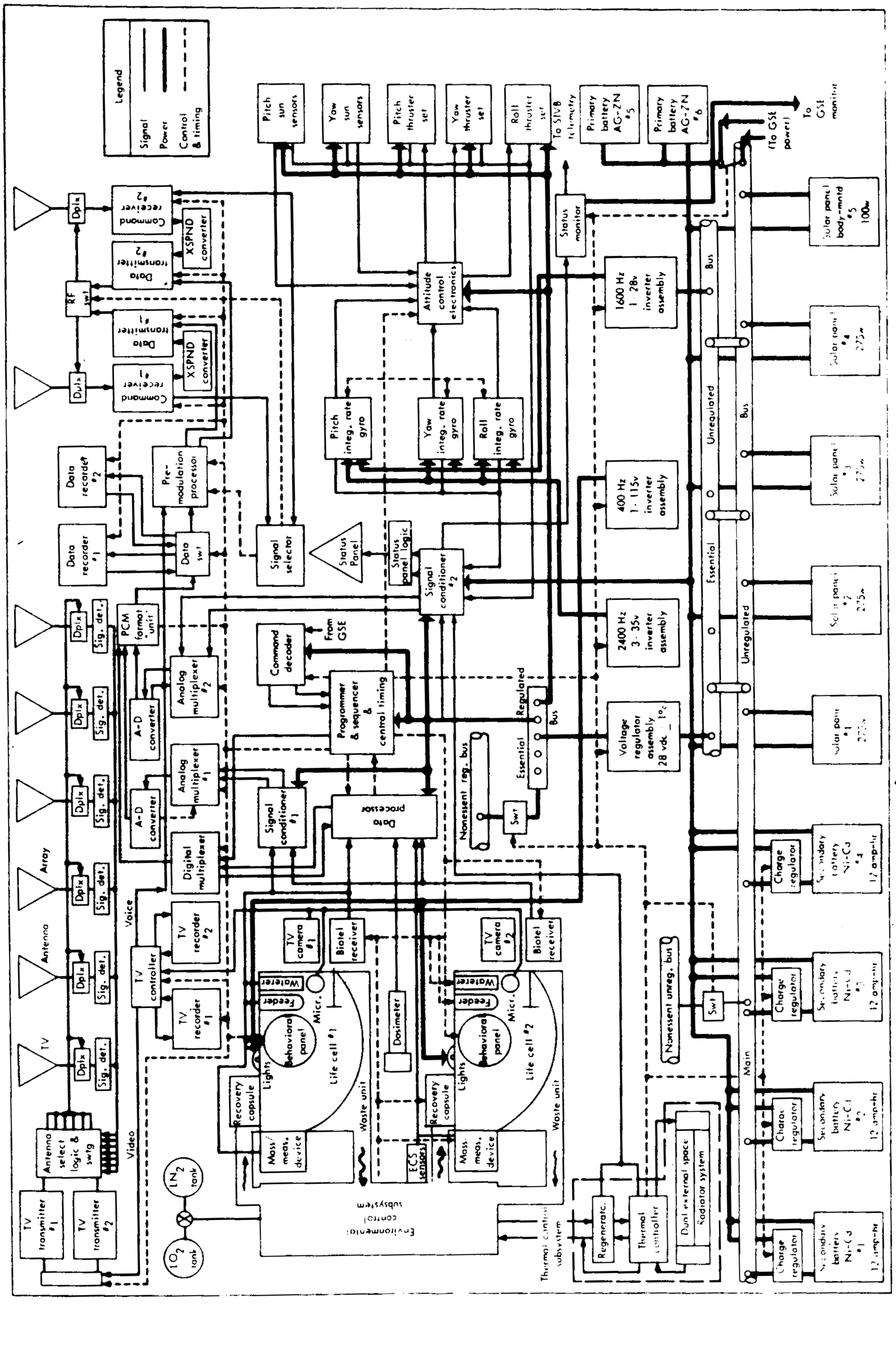

Figure 3. - Spacecraft system block diagram

ENGINEERING EXPERIMENTS

Introduction of additional engineering experiments into the existing Orbiting Primate Spacecraft (OPS) design ceneters around the desire to utilize the versatile capabilities of such a spacecraft and to evaluate and improve the performance of the life support equipment by:

(1) Reducing component weights to a minimum.

(2) Reducing expendable material weights to a minimum.

(3) Increasing mission lifetime.

(4) Increasing system reliability.

(5) Increasing the cost effectiveness of the program.

(6) Installing ECS components in parallel loops into the presently designed Life Support System, to obtain design and performance data under long term weightless conditions while the system is actively supporting two primates for one year.

Additional engineering experiments that could be flown together with the prime experiment and its support equipment have been reviewed and the following have been selected as candidate examples.

(1) Active CO_2 management system consisting of

(a) CO_2 concentration unit (Zeolite bed).

(b) CO_2 reduction unit (Bosch reactor along with the possible inclusion of a Sabatier reactor as backup).

(c) Water electrolysis unit used to convert the H_2O byproduct of the CO_2 reduction unit into O_2 and H_2.

(2) Waste water recovery unit.

(3) UV/IR Gas Analyzer unit.

(4) Atmospheric contaminant analysis experiment.

Any or all of the above listed six experiments can be added to the existing OPS environmental control and waste management system, figure 4, in such a manner that failure of any or all of the experiments would not endanger the prime experiment. In addition, two or more of these experiments can be operated simultaneously for extended periods of time.

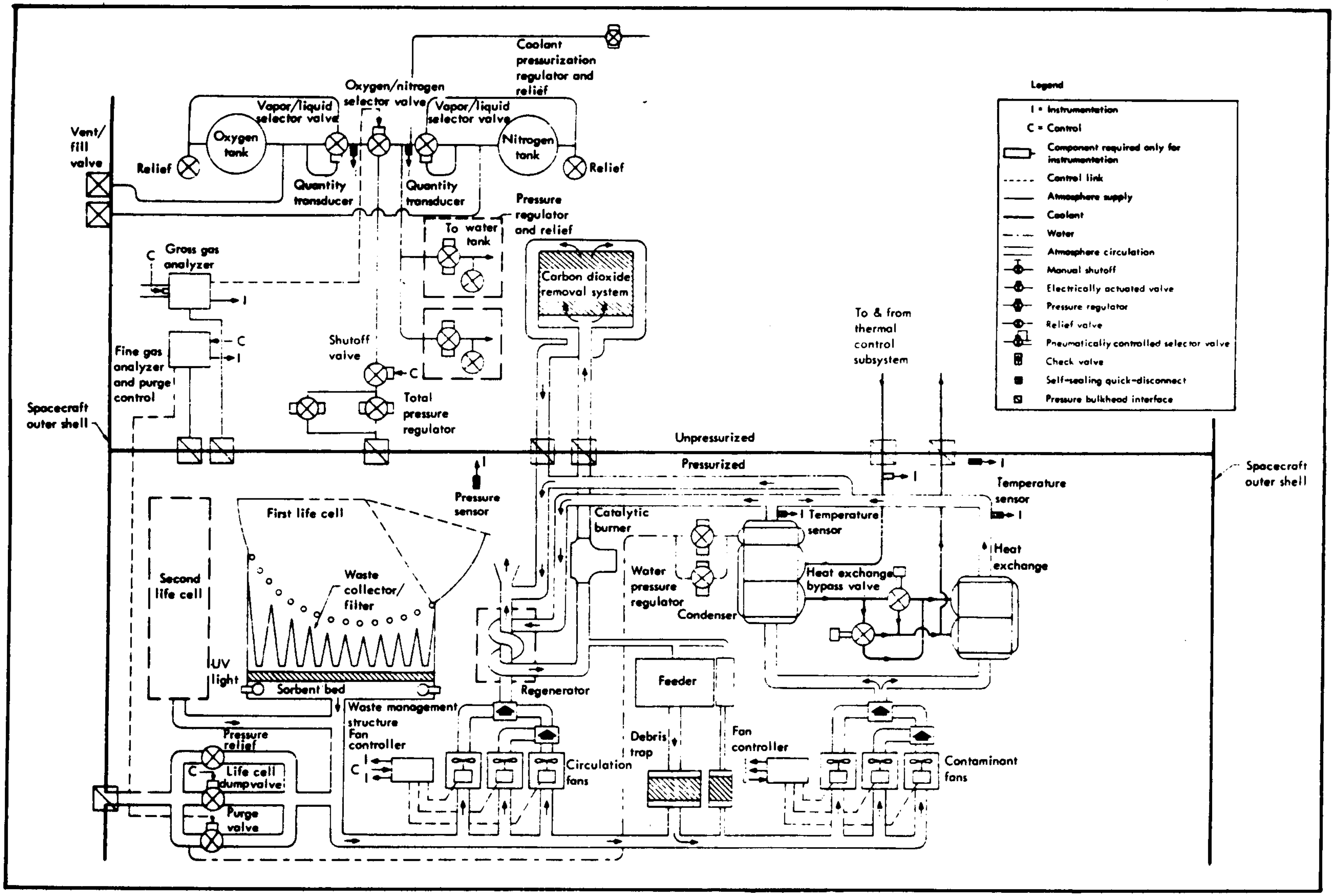

Figure 4. - Environmental control, waste management and thermal control

CO_2 Management System

The following is a brief description and performance summary of the first candidate engineering experiment. The active CO_2 management system actually contains three separate devices; however, they will be discussed under a single heading, since each contributes to the active closed loop management of CO_2.

CO_2 Concentration Unit. - This unit is basically a regenerable CO_2 absorption device. The present Orbiting Primate Spacecraft (OPS) CO_2 management equipment consists of LiOH canisters that absorb and hold the CO_2 as it is generated by the animals. Since these canisters cannot be regenerated, their weight and volume requirements are directly proportional to the length of the mission. The candidate CO_2 concentration unit consists of two Zeolite beds and two silica gel desiccant beds along with the required pumps and plumbing. Figure 5 shows a simplified schematic of the system. The unit processes a portion of the cabin air through one desiccant bed to first remove moisture and through one Zeolite bed to absorb CO_2. While this is in progress, the second desiccant bed is being dried and the second Zeolite bed is being desorbed of CO_2. The CO_2 removed during desorption is stored in an accumulator for use either in a CO_2 reduction unit or dumped to space vacuum. After a prescribed period of time, the desorbed beds are switched from desorption to absorption and the absorbing beds are placed on a desorption cycle thereby providing constant CO_2 control.

Waste heat from the OPS Life Support System can be used during normal unit operation to condition the beds to the proper operating temperature, and storage battery solar cell power is used for a monthly high temperature Zeolite bed purge.

Table 1 presents a general summary of the CO_2 concentration unit experiment and its effects on the OPS design.

CO_2 Reduction Unit. - This unit is a chemical reactor in which nearly pure CO_2 is reacted with hydrogen to produce water and either carbon or methane gas. If carbon is formed, the reaction, named the Bosch process, produces the following chemical reaction:

$$CO_2 + 2H_2 \longrightarrow 2H_2O + C$$

Figure 6 shows a simple block diagram of the Bosch reaction. The H_2 required for the reaction is supplied from a water electrolysis cell which in turn uses the water byproduct of the CO_2 reduction unit.

If on the other hand the chemical reaction produces methane gas, the reaction, called the Sabatie process, produces the following chemical reaction:

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$$

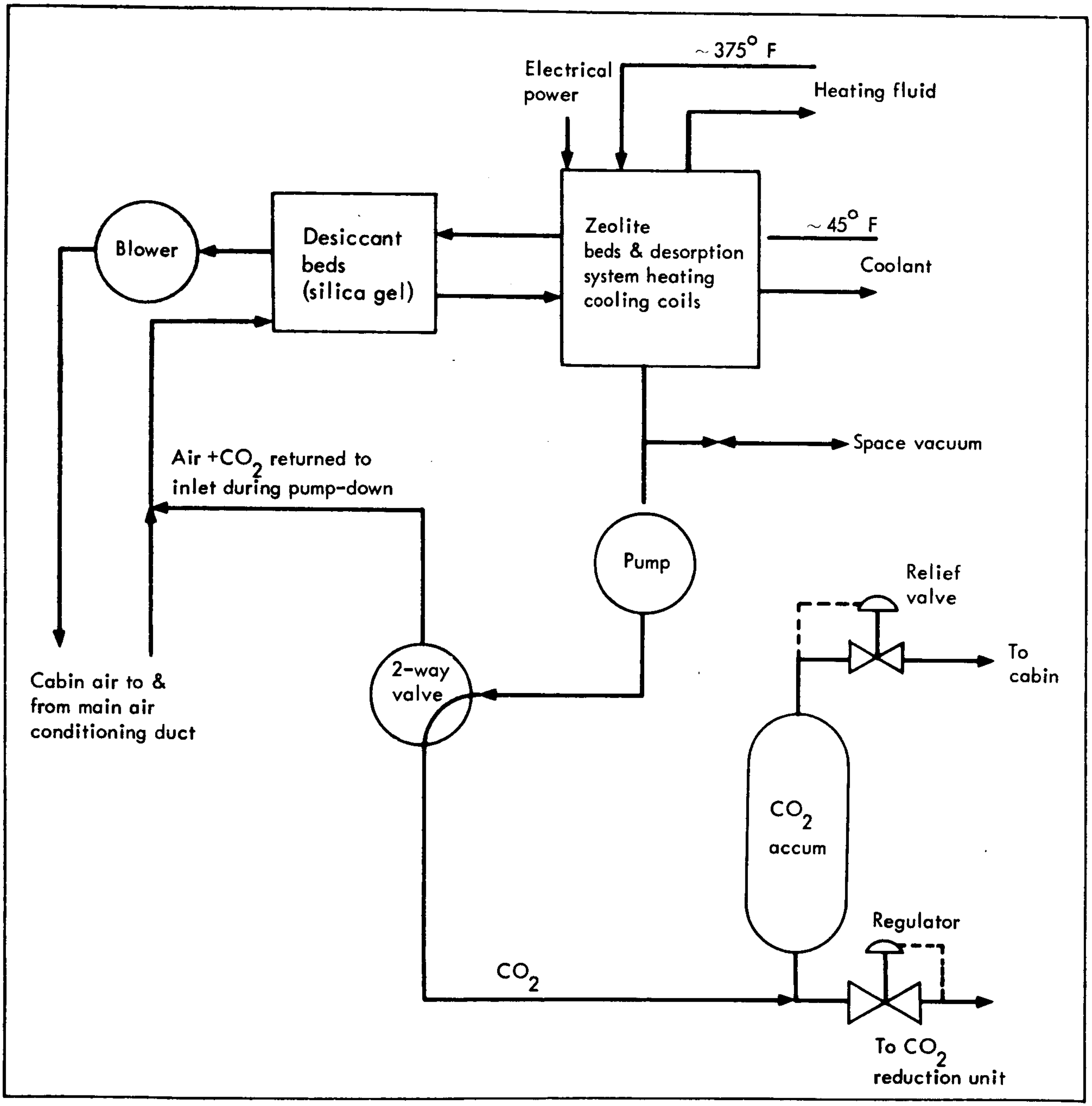

Figure 5. - CO_2 concentration unit

TABLE 1. - CO_2 CONCENTRATION (ZEOLITE BED) UNIT

Objective: Provide an active CO_2 concentration system that could be used to feed near pure CO_2 to a reduction unit that would produce H_2O. The overall objective is to study a closed Environmental Control System gas path.

Development Status: Hamilton Standard Division, United Aircraft Corporation, has developed a working prototype that is now being tested at Langley Research Center as a part of the overall LSS test program.

Experiment Characteristics	Effect on Spacecraft Design
Volume: 3.0 cu. ft. Weight: 78.0 Lb. Power: 350 watts for four hours once/month	1. Additional electric power capacity required. 2. Additional telemetry monitoring channels required.
Data Requirements: Real time data readout sufficient to monitor safe operation of the system. Actual system performance will be monitored with existing instrumentation.	3. Additional telemetry command channels required. 4. Additional cooling capacity required during absorption.
Control Requirements: Control to provide complete isolation from primary L:OH canister CO_2 management system, when required.	5. Additional radiator area on external surfaces of spacecraft required. 6. Break in pressure shell required in order to vent CO_2 when reduction unit is not in use.
Operational Requirements: This experiment is to be run on a parallel loop basis with the L:OH canisters and is to be sized to take over CO_2 management completely from the L:OH system.	7. Heat required during desorption.

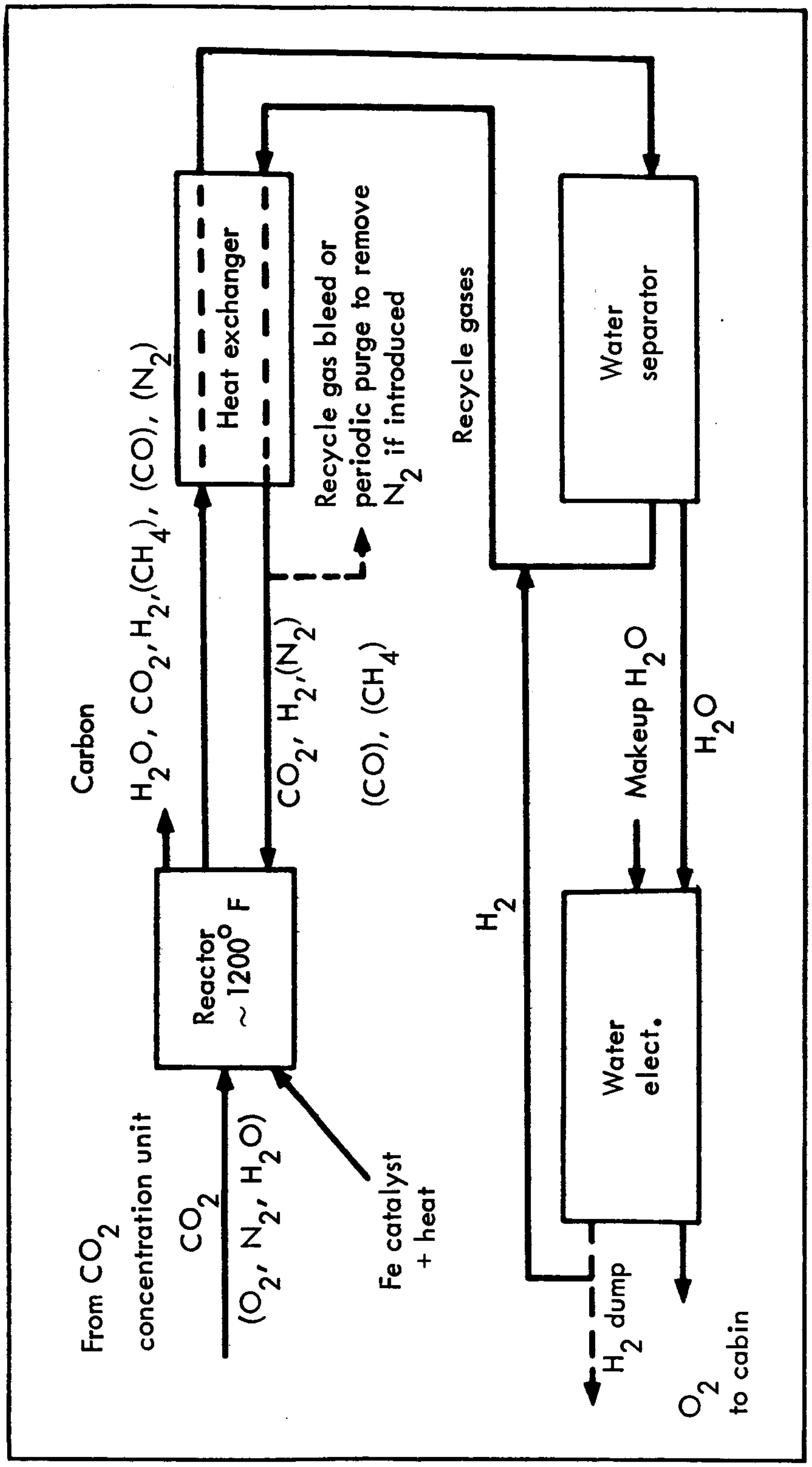

Figure 6. - Bosch CO_2 reduction system

Figure 7 shows a simple block diagram of the Sabatier reaction. As with the Bosch reaction, the H_2 required is supplied from a water electrolysis cell which in turn uses the water byproduct of the CO_2 reduction unit.

Table 2 presents a summary of the CO_2 reduction unit which consists of both a Bosch reactor and a backup Sabatier reactor.

Water electrolysis unit. - This device consists of a reactor that converts water into H_2 and O_2. The particular unit selected uses the double membrance concept, a water H_2SO_4 electrolyte and platinum black electrodes. Figure 8 shows the basic cell layout and figures 6 and 7 show how the water electrolysis unit is integrated into the CO_2 management system. Table 3 presents a summary of a proposed flight unit.

Waste water recovery unit. - The waste water recovery unit proposed as a flight experiment consists of an air dried wick evaporator, an air loop heater, a condenser and a water separator. Figure 9 depicts a block diagram of the system with the evaporator being fed from the OPS liquid waste condenser, and the recovered water being stored in existing OPS tankage. Table 4 presents a summary of the unit as proposed for light onboard the OPS.

UV/IR gas analyzer system. - This experiment provides a redundant method for determining the concentration of the principal atmospheric gases within the environmental system. The presence of two different gas sensor systems, each operating on vastly different principals, provides a check on both systems; in addition, the output of both systems may indicate if some unforeseen substance is influencing the output of one sensor.

The UV/IR Gas Analyzer System senses: (1) the concentration of CO_2 by the absorption of IR energy in a sample optical cell, (2) the concentration of O_2 and H_2O by the absorption of UV energy in a sample optical cell, and (3) the concentration of N_2 by measuring the total gas pressure and subtracting the partial pressures of CO_2, O_2, and H_2O.

A block diagram of this unit is shown in Figure 10. The bolometer is the IR detector; the Xenon lamp is the UV source while the photomultiplier is the UV detector. Table 5 presents a summary of the proposed experiment.

The UV/IR Sensor System operates by determining the optical absorption of specific wavelengths of UV and IR energy. The primary OPS atmospheric control mass spectrometer determines the composition of gaseous materials with atomic mass numbers 18 (H_2O), 28 (N_2O), 32 (O_2), and 44 (CO_2). Operation of both systems provides operational experience, control back-up in case either fails, and increases the certainty with which the atmospheric composition is known. In addition should any unexpected gases appear in the atmosphere which might affect one sensor, it probably would not affect the other. Thus in the event of some catastrophe, the probability of acquiring knowledge of the nature of the emergency would be increased.

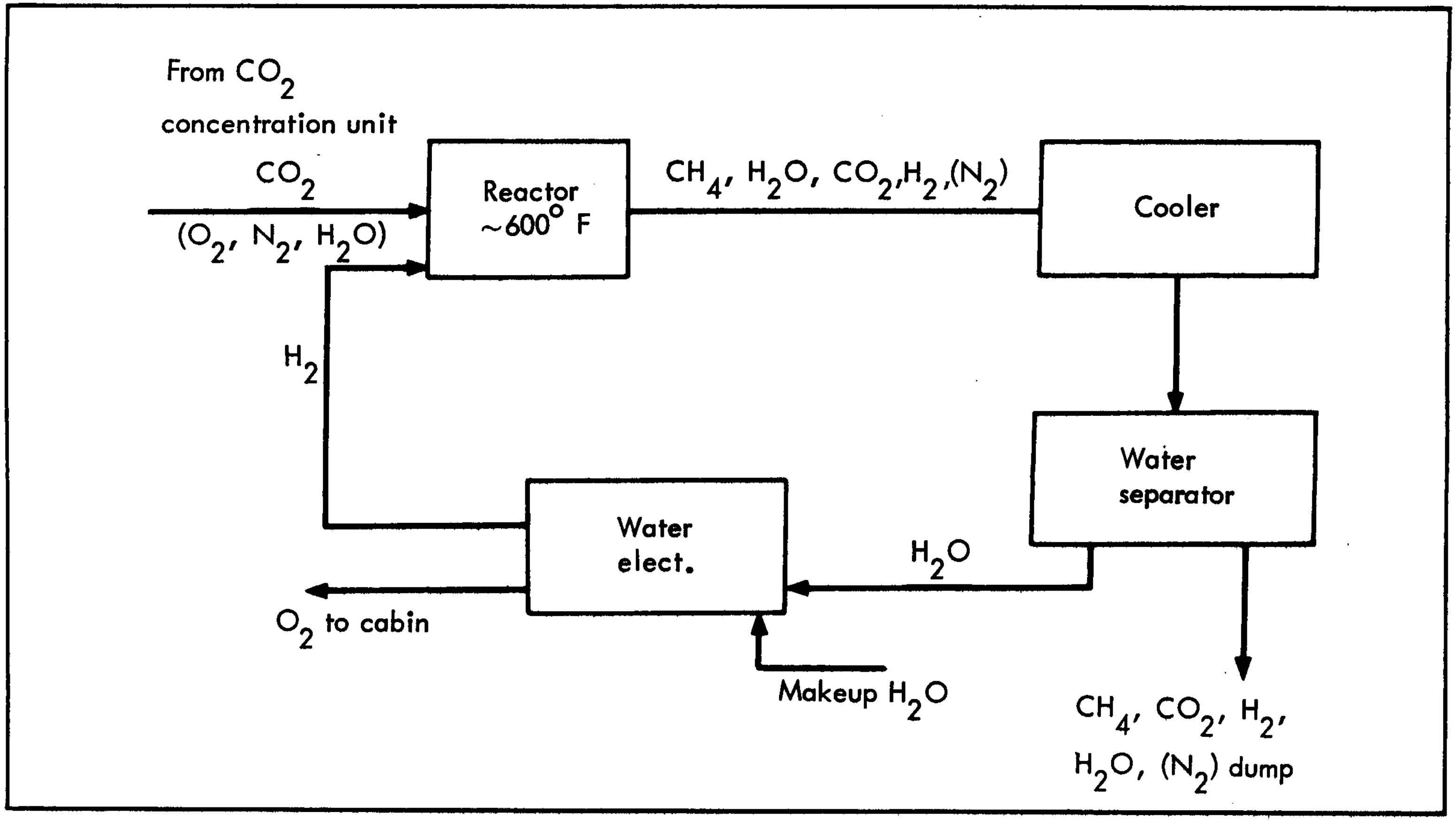

Figure 7. - Sabatier CO_2 reduction system

TABLE 2. - CO_2 REDUCTION UNIT (BOSCH REACTOR PRIMARY - SABATIER, SECONDARY)

Objective: Provide a CO_2 reduction system that could be used to convert CO_2 to H_2O for use in an ~~O_2 (and H_2)~~ producing Water Electrolysis Cell.

Development Status: Electromechanical Division, Thompson Ramo Wooldridge, has developed a working prototype that is now being tested at Langley Research Center as a part of the overall LSS test program.

Experiment Characteristics

Volume: 1.5 Cu ft
Weight: 46.0 lb
Power: 230 watts (115 watts/unit)

Date Requirements:

Real time data readout sufficient to monitor safe operation of the system plus data sufficient to determine system performance.

Control Requirements:

Control to provide real time switching of system into and out of ECS loop. When CO_2 reduction unit is not in the ECS loop, CO_2 dump to space vacuum is to be provided.

Operational Requirements:

This experiment is to be run in conjunction with the CO_2 concentration experiment. However, the CO_2 concentration experiment can be operated without the CO_2 reduction loop by dumping the CO_2 to vacuum.

Effect on Spacecraft Design

1. Additional electric power capacity required.
2. Additional telemetry monitoring channels required.
3. Additional telemetry command channels required.
4. Additional cooling capacity required.
5. Additional radiator area on external surface of spacecraft required.

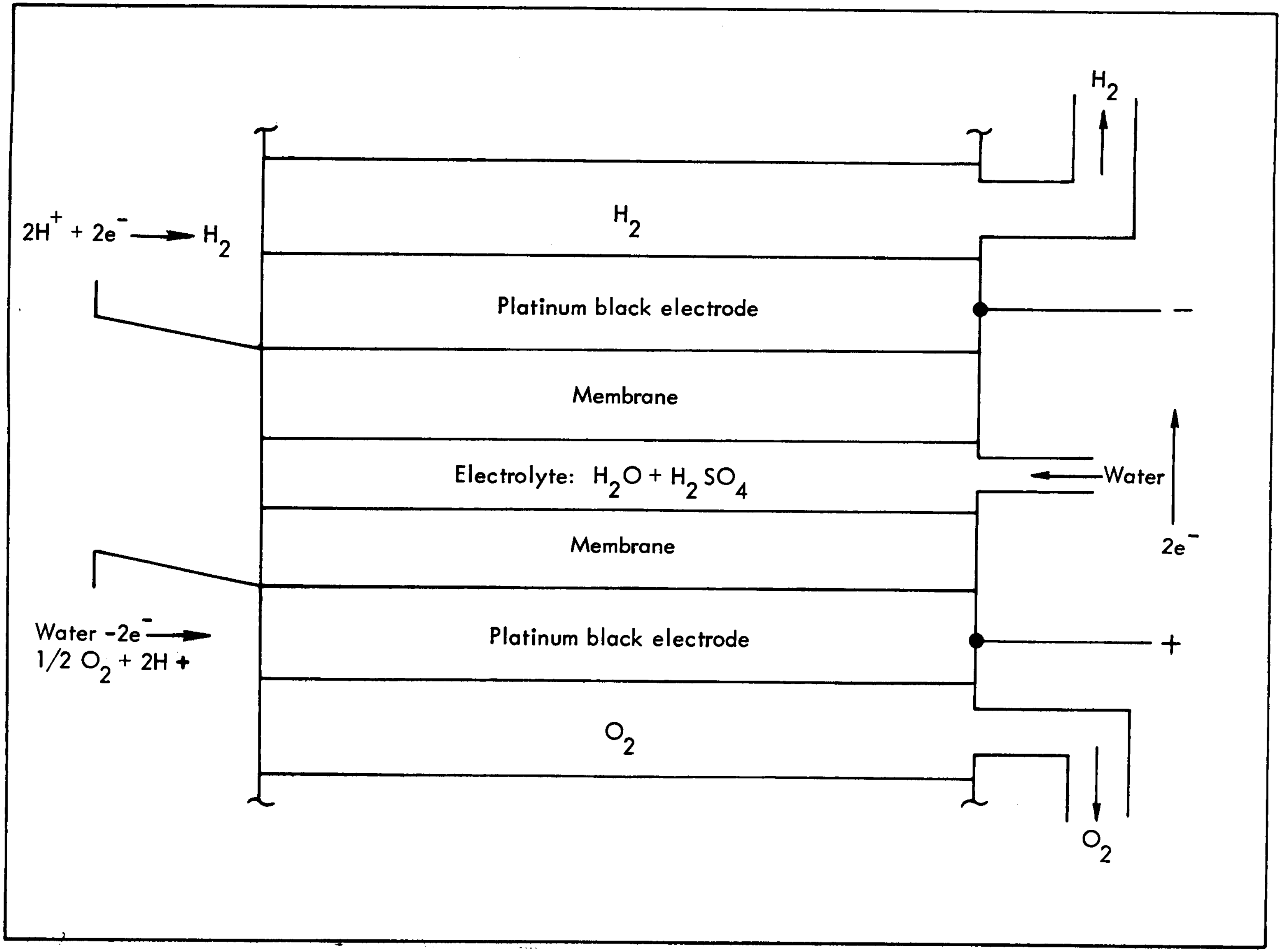

Figure 8. - Double membrane water electrolysis cell

TABLE 3. - WATER ELECTROLYSIS UNIT

<u>Objective:</u> Provide a water electrolysis unit that can convert the H_2O produced by a CO_2 reduction unit into breathing O_2 and H_2.

<u>Development Status:</u> General Electric Company, Valley Forge Technical Center, has developed a working prototype of a double membrane cell stack that uses H_2SO_4 as the electrolyte. This unit is being tested at Langley Research Center as a part of the overall LSS test program.

<u>Experiment Characteristics</u>

Volume: 0.6 Cu ft
Weight: 8 lb
Power: 90 watts

<u>Data Requirements:</u>

Real time data readout sufficient to monitor safe operation of the system plus data sufficient to determine system performance.

<u>Control Requirements:</u>

Control to provide real time switching of system into and out of ECS loop along with CO_2 reduction unit.

<u>Operational Requirements:</u>

This experiment is to be run in conjunction with the CO_2 concentration experiment. However, the CO_2 concentration experiment can be operated without the electrolysis and CO_2 reduction loop by dumping the CO_2 to vacuum.

<u>Effect on Spacecraft Design</u>

1. Additional electric power capacity required.
2. Additional telemetry monitoring channels required.
3. Additional telemetry command channels required.
4. Additional cooling capacity required.
5. Additional radiator area on external surfaces of spacecraft required.

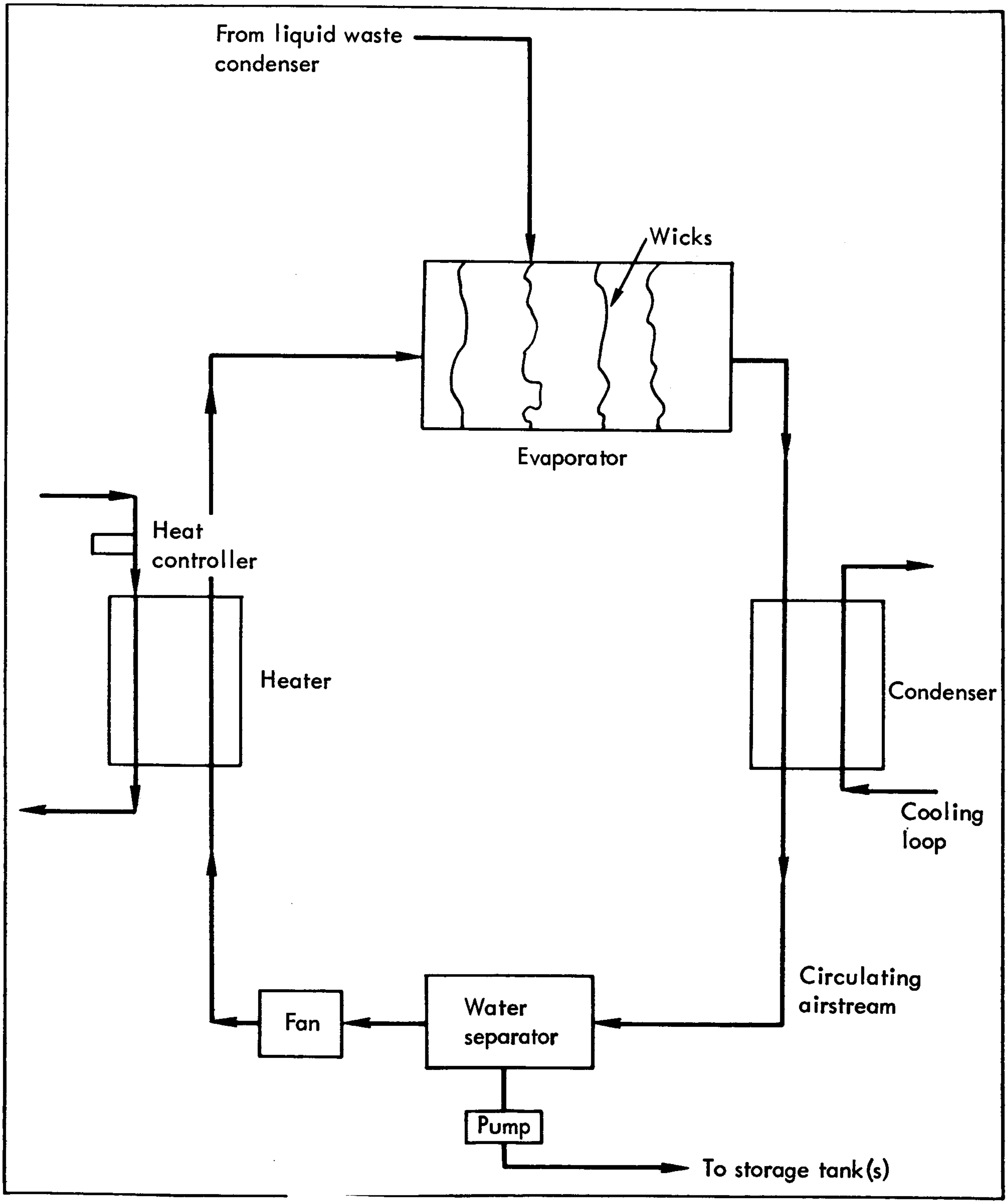

Figure 9. - Water recovery unit

TABLE 4. - WATER RECOVERY UNIT

Objective: Provide a water recovery unit that is capable of accepting liquid from the ECS condenser, process it into potable water, and deliver it to the primate water supply.

Development Status: Hamilton Standard Division, United Aircraft Corp., has developed a working prototype that is now being tested at Langley Research Center, as a part of the overall LSS test program. Unit is designed for 1"g" operation but could be modified for 0"g" conditions.

Experiment Characteristics

Volume: 3.0 CU ft
Weight: 41.5 lb
Power: 30 watts

Data Requirements:

Real time data readout sufficient to monitor safe operation of the system plus data sufficient to determine system performance.

Control Requirements:

Control to provide real time switching of system into and out of the ECS waste water purge line to vacuum along with control of heat to ECS air flow and cooling to condenser unit.

Operational Requirements:

If waste heat is to be used for air evaporator heating, system could be operated continuously. Checks must be made so that the unit is not producing contaminated liquid before liquid is dumped into common supply. A separate storage tank may be required.

Effect on Spacecraft Design

1. Additional electric power capacity required.
2. Additional telemetry monitoring channels required.
3. Additional telemetry command channels required.
4. Additional cooling capacity to cool the condenser required.
5. Waste heat from existing ECS or heating (electric) coils required to heat evaporator air flow.
6. Tap-off of existing ECS air flow required for evaporator.

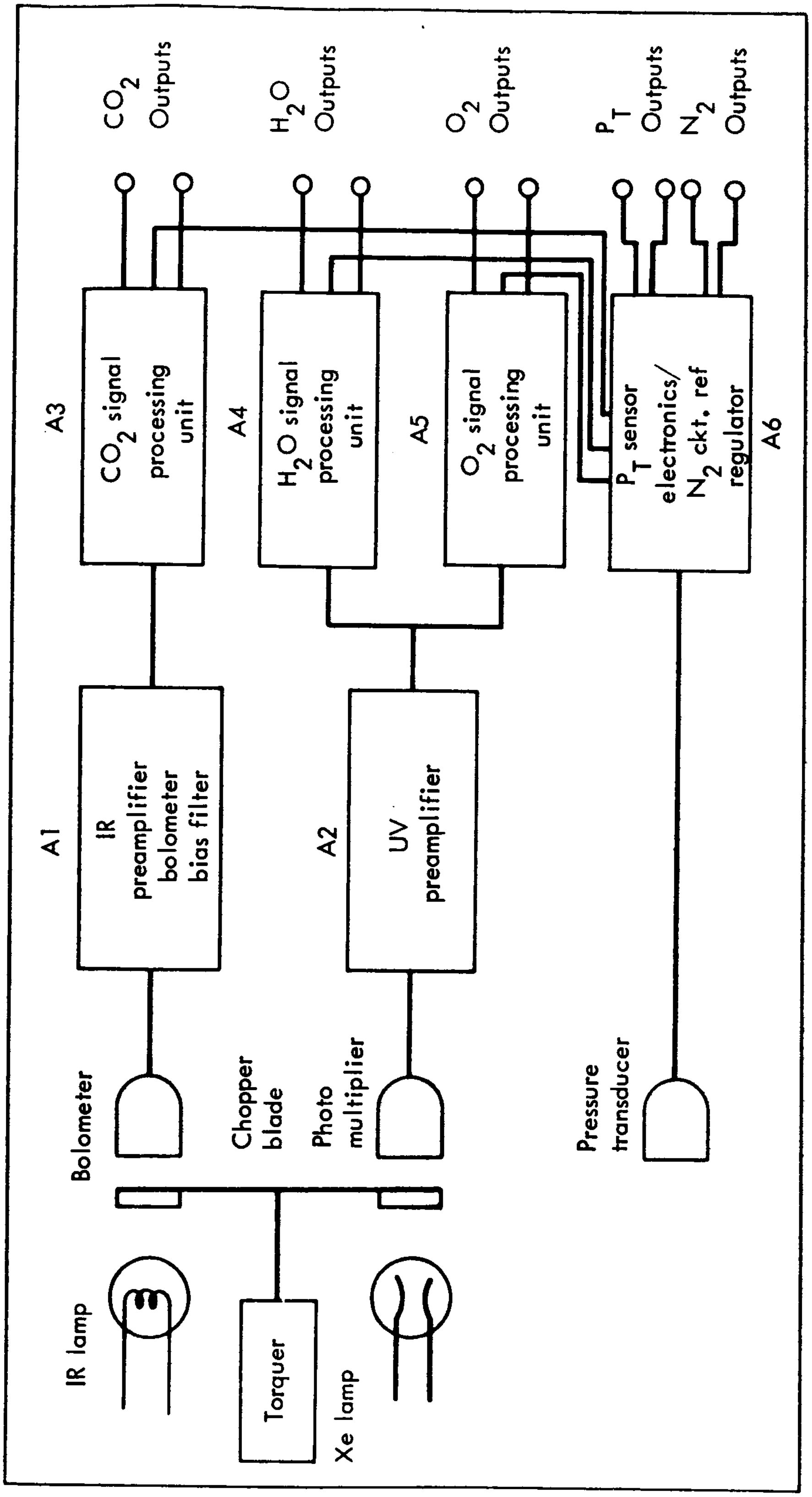

Figure 10. - Two-gas sensor block diagram

TABLE 5. - UV/IR GAS ANALYZER SYSTEM

Objective: Provide performance comparison for the UV/IR Gas Analyzer to the Mass Spectrograph Gas Analyzer and to provide long term flight experience for the UV/IR Gas Sensor System.

Development Status: The UV/IR Gas Analyzer System is being developed by Perkin Elmer under NASA contract. Gas Sensor provides PO_2, PH_2O, PCO_2, P total and PN_2.

Experiment Characteristics	Effect on Spacecraft Design
Size: 3.5" x 3.9" x 8"	The present OPS spacecraft design requires no major modifications to accommodate weight, power data and command requirements.
Weight: 6.5#	
Power: 28 Volts DC - 5W	
Data output 5 analog channels 0 to 5V sample rate 1/min.	
Command control On/Off	
EVA Requirements: None	

<u>Atmospheric contaminant analysis experiment</u>. - The objective of this experiment is to determine the chemical and biological nature of the primate environment as a function of time during the mission. In particular, it is desired to return samples to earth for analysis.

The primary emphasis is to determine the chemical, biological, and particulate composition of the atmosphere in the living chamber as a function of time. The chemical composition will include the primary gases, oxygen and nitrogen; the major trace gases, water and carbon dioxide; and those trace gases which could be detrimental to life such as: carbon monoxide, ammonia, hydrogen sulfide, and a variety of hydrocarbons. The biological composition will include a determination of the number and kinds of bacteria, fungi, and if possible, virus present. The particulate composition will include a particle count and a determination of the particulate composition. In addition, samples of the water reservoir will be returned for chemical and biological analyses by conventional techniques.

The preliminary design of the OPS provides a Perkin-Elmer mass spectrometer for the control of the oxygen partial pressure. This instrument also monitors the partial pressure of nitrogen, carbon dioxide and water; these data are telemetered to earth in the existing spacecraft design. Thus the Northrop design already monitors the principal atmospheric constituents.

The biological specimens (bacteria, fungi, and virus) are fragile and will not survive in significant numbers more than a few days after the sample is collected. Thus the sampling will take place just prior to the recovery of the EVA packages. Figure 11 shows a schematic of a collection unit.

An air sample is drawn through the collection flask by a vacuum on the output line (either space or a closed evacuated bottle for greater system reliability). The flask contains a sterilized nutrient which had previously been sealed with optimum internal conditions for the preservation of the nutrient. The diffuser spreads the air flow across the nutrient which captures some of the air-borne biological samples. At least two collection flasks will be required, one with a nutrient for bacteria and one with a nutrient for fungi. The biological materials will grow on the nutrient; the samples should reach the analysis laboratory within 48 hours. Additional bacteriological samples will be available in the fecal matter present in the recovery capsule.

The valves on the bacteriological sampling system can be conventional valves or glass membranes which are broken to open; a squib would then be used to seal a metallic portion of the tubing. During EVA, the entire sample package is removed; all the plumbing lines contain simple disconnects.

A water sample will also be collected just prior to the EVA; provision will be made for collection of one or more samples during the mission.

The atmospheric samples will be collected in 50 ml (3 cubic inches) containers which provide a sample sufficient for laboratory analysis using a gas chromatograph and a mass spectrometer. These containers will be evaluated and outgassed prior to launch. The container will be opened to the environmental atmosphere to collect a sample and then sealed off, as mentioned previously. A micropore filter will be in the neck of the collection container

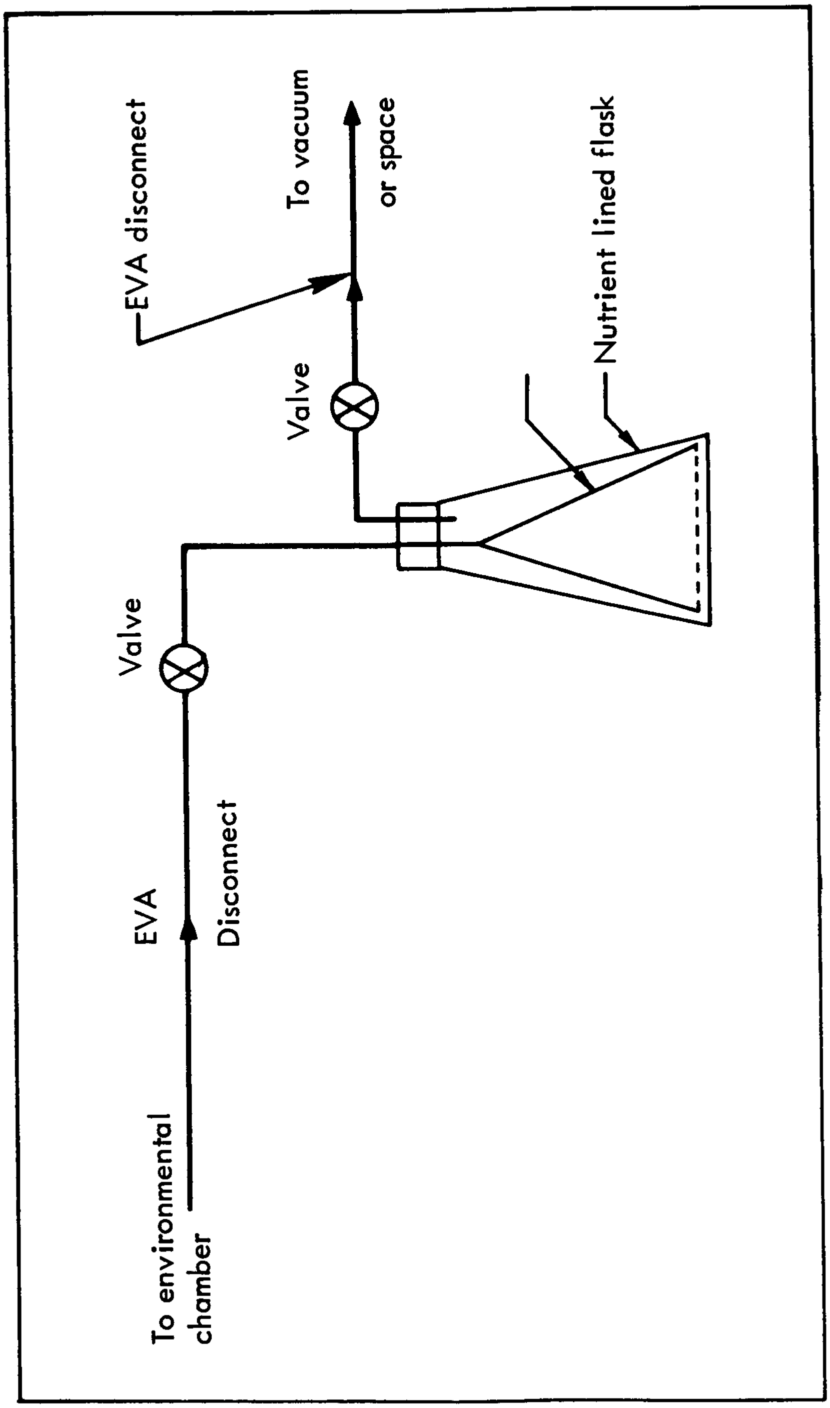

Figure 11. - Biological sample collector

to exclude particulate matter and bacteria from the collection container; this filter will be sealed off from the container. The filter will be returned and analysed for particulate matter.

Atmospheric samples will be collected at one week intervals throughout the mission. One or two water samples will be collected at the discretion of the Principal Investigator. A final water sample and the two biological samples will be collected just prior to the EVA. When the astronaut recovers the primates, he will also retrieve the collection package for return to earth. Table 6 presents a summary of the proposed experiment.

There are no serious questions regarding the validity of the data obtained from the onboard mass spectrometer or from the collected biological or water samples. There are problems associated with the determination of trace quantities of gas after storage.

The laboratory analysis of gases using a gas chromatograph and a mass spectrometer is a powerful technique that can detect and measure quantities of gas down to the parts per billion range. The laboratory methods measure the gas fed into the instrument. However, the problem is; is this gas composition the same as the gas when it was collected? Whenever a gas is stored in a container some of it will adsorb on the container walls; some of it will react chemically with the walls. In the case of active gases present in trace amounts, they may be completely removed from the stored gases.

As an example, hydrogen sulfide, (H_2S), will react with metallic oxides in either metal or glass containers and form metallic sulfides which are chemically bound to the surface; the reaction liberates water which is a negligible fraction of the water vapor already present. Becuase of this reaction, most of the H_2S present in an air sample may be removed by unwanted reactions within 72 hours. In a similar fashion, ammonia (NH_3) will also be removed from a container. There is no known way to reverse these reactions and recover the gas concentrations.

The various hydrocarbon gases may be adsorbed on the container walls; however, it appears that they can be desorbed with the application of heat.

A potential analytical technique would be the introduction of a small amount of reactive metal (similar to a vacuum tube getter) into the container to collect the contaminants. This metal could then be vaporized and analysed using the techniques of mass or optical spectroscopy.

Further laboratory study is recommended to determine if the trace gases can be quantitatively measured and if the experiment technique will produce meaningful results.

Recommended Development Area

All of the candidate engineering experiments are in the development phase at present. The CO_2 management system concept is under test at Langley Research Center as a part of an overall life support system that is capable of supporting

TABLE 6. - ENVIRONMENTAL CONTAMINANT ANALYSIS EXPERIMENT

Objective: Determine chemical, biological, and particulate composition of atmosphere and water of primate environment as a function of time in orbit.

Development Status: All components of sampling equipment are state-of-the-art. Further laboratory work required to verify validity of analysis techniques.

Experiment Characteristics	Effect on Spacecraft Design
Size: 6" x 7" x 12" Weight: 10 lb Power: 50 watt-hrs/mission	1. Additional external EVA Package. 2. Additional lines through pressure chamber.
Data Requirements: Indicate Sampling Occurred	3. Additional control commands required.
Control Requirements: Ground Control to initiate sampling	4. Additional performance verification required.
Operational Requirements:	5. Negligible additional power required.

Obtain 56 atmospheric samples in pre-evacuated chambers. 1" OD x 4" long, each with micropore filter. Take sample approximately each two weeks.

Take water sample, bacteria culture, fungus culture just before primate recovery. Take one water sample when desired.

Perform EVA to recover Package.

four men for extended periods of time under space conditions (except zero gravity).

Some difficulties have been encountered in the Bosch Reactor portion of the CO_2 reduction system relative to the removal of the pure carbon from the reactor structure. Additional development work is required in this area.

Corrosion problems are being experienced with the water electrolysis cell thus limiting this unit's useful life. Water electrolysis cell development work is continuing and can be expected to produce an increasingly useful lifetime.

For the waste water recovery unit, an air dried wick type evaporator is also on test at Langley Research Center in the same life support system. Wick contamination is a problem at present that will require more development activity. At present, wick lifetime is low.

For environmental contaminant analysis, Northrop has conducted surveys of T-38 and F-5 airplane cockpit atmospheres using a technique similar to that proposed for the OPS. However, only a limited number of contaminants were identified. Further work is required to develope a more refined and reliable technique suitable for an extended period unmanned orbital flight experiment.

All the candidate experiments require design effort for completing the mechanization and packaging to:

(1) Provide the reliability and life expectancy necessary for a flight experiment.

(2) Provide a small and light-weight package with minimized electrical power requirements.

Preliminary Equipment List

Table 7 is a summary of experiment hardware with estimates of weight, volume and power requirements. These estimates reflect hardware that could be installed in the existing OPS design and flown together with, but non-interacting, or in support of the original experiment (two unrestrained primates).

Effects on Orbiting Primate Spacecraft

All of the candidate engineering experiments discussed can be accommodated on board the OPS simultaneously. Figure 12 depicts the physical location of each of the experiments within the Northrop Orbiting Primate Spacecraft. All experiments are located within the pressure shell except for the atmospheric contaminant analysis unit which is located on the top outer shell adjacent to the primate recovery capsules. This location permits EVA recovery of this unit at primate recovery time.

TABLE 7. - PRELIMINARY EXPERIMENT EQUIPMENT LIST

Experiment	Weight	Volume	Power (Watts or as Indicated)
CO_2 Management System			
CO_2 Concentration Unit	78.0	3.0	350 watts for four hours once/month
CO_2 Reduction Unit (Includes one Bosch Unit & one Sabatier Unit)	46.0	1.5	230
Water Electrolysis Unit	8.0	0.6	85
Waste Water Recovery Unit	41.5	3.0	30
UV/IR Gas Analyzer Unit	6.5	0.1	5
Atmospheric Contaminant Analysis Unit	10.0	0.3	50 watt-hours
TOTALS	190.0 lb	8.5 ft	350 watts plus 1400 watt-hours once per month

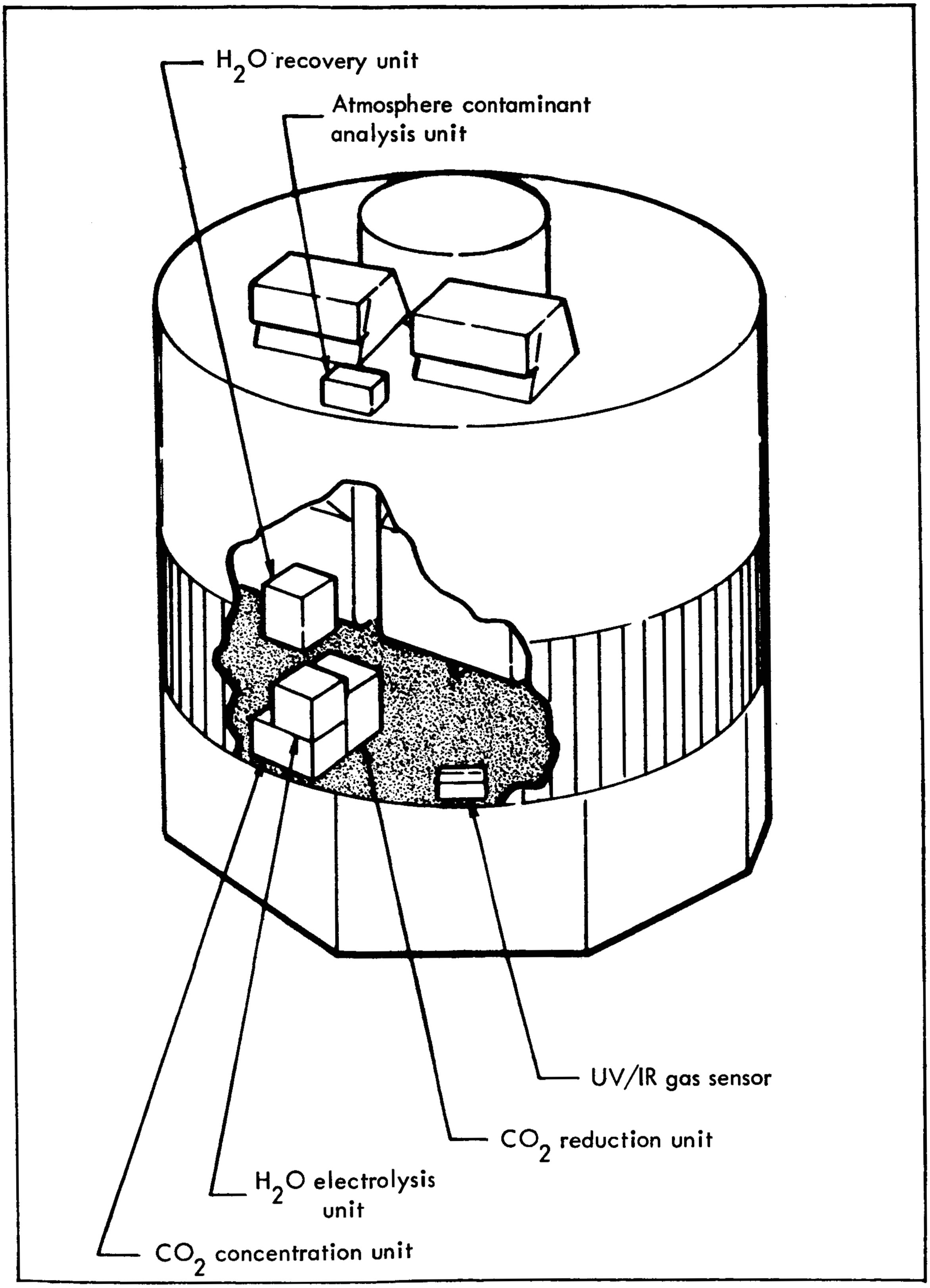

Figure 12. - Possible Locations for additional ECS engineering experiments

The six units weigh 190 lbs. and occupy approximately 8.5 cubic feet of volume. Power consumption is approximately 350 watts assuming all units are operating plus 1400 watt-hours (350 watts for 4 hours) once per month to recondition the Zeolite beds in the CO_2 concentration unit. The existing OPS power system was designed with a 150 watt excess capacity alternate use. Using this excess capacity, an additional 53 square feet of solar panel area will be required along with an additional 70 lbs. of batteries. The additional solar panel area weight is 63.5 lbs. No additional power system enlargement is needed for the 1400 watt-hours requirement once per month to recondition the Zeolite beds since a slightly deeper depth of battery discharge can be tolerated for these four-hour periods with complete battery recovery being made in approximately one day after each monthly Zeolite recondition cycle.

Assuming an additional 40 lbs. for structure, plumbing, ducting, and cabling to accommodate these added experiments, a total system weight increase of 363.5 lbs. is anticipated. The present OPS command and telemetry system can accommodate the relatively few additional data points and commands that will be required to operate and monitor the experiments. Additional detailed analysis will be required to accommodate experiment thermal control requirements. This can be readily accomplished by providing proper heat sinks, routing of spacecraft waste heat to the using devices and resizing space radiator to accommodate the increased thermal load. No major changes to the attitude control system are anticipated since the bulk of the added weight will be located near to the spacecraft center of gravity.

Additional Flight Experiments

The six experiments detailed in preceding paragraphs are by no means all of the additional experiments that can be accommodated onboard the OPS during its orbital mission. The OPS is, in reality, an orbiting bus that consists of an attitude controlled stable platform, a long life power generation system, a completely independent life support system capable of supporting small animals for extended time periods and all of the other hardware required to support these systems. Such a bus could support engineering experiments ranging from special solar cell arrays to experimental space radiators utilizing fusible materials. Experiments that record micrometeorial activity or solar flare over long time periods are entirely feasible especially when considering that experiment samples can be recovered and returned to earth. Following is a brief list of engineering type experiments that could be flown on an OPS mission:

(1) Special solar cell arrays consisting of advanced solar cell devices that require long term testing in the deep space environment. Switching and power monitoring devices can be designed into the experiment so that cell performance would be monitored from ground stations. Samples of the cells could be returned to earth at rendezvous time.

(2) Space radiators utilizing fusible materials can be readily mounted to external surfaces of the OPS skin. Northrop has recently completed a

feasibility study and laboratory hardware phase that resulted in designs of fusible material radiators to be tested in earth orbit. These devices can be flown on the unmanned OPS since recording performance simply involves the recording of radiator temperature against a time base. The radiators could be retrieved, if desired, at primate retrieval time through an astronaut EVA.

(3) Micrometeoroid detection and/or collection is also entirely feasible using the OPS as a long term orbiting collection station. Special meteoroid detecting and collecting surfaces can be installed on portions of the OPS skin before launch and monitored from ground stations throughout the entire one year period. At the end of the mission, an astronaut could collect any captured micrometeroids and any sample portions of the special skin, if required. A solar radiation detection experiment could be handled in a similar manner.

(4) Thermal control coatings are well suited as engineering experiment candidates to be flown on the OPS. The spacecraft is sun oriented to close tolerances and the one year mission offers ample exposure time. Coating performance can be indirectly monitored throughout the exposure period by supplying the surfaces with temperature indicators which are read out through the OPS telemetry system. At the end of the mission, an astronaut can collect coating chips at primate recovery time.

Summary

Many worthwhile engineering type experiments can be flown on board the OPS without endangering or interacting with the primate experiment. With the proper selection, many of these experiments could be flown simultaneously.

BIOLOGICAL EXPERIMENTS

The Orbiting Primate Spacecraft (OPS) has been designed to meet the requirements of a specific biological experiment. However, the gross requirements for a large class of orbiting biological experiments are similar. This section presents a description of several specific biological experiments and indicates the type of spacecraft modification required to effect experimental support. The experiment descriptions are the Principal Investigator's desired configurations; no compromises with mission or spacecraft requirements have been made.

Three orbiting primate experiments and a mouse colony experiment are described.

Automated Primate Research Laboratory
Principal Investigator - N. Pace, Ph.D
University of California, Berkeley

Experiment description. - The experiment measures the cardio-vascular and general metabolic response of two restrained Pig-Tailed monkeys (Macaca nemestrina) as a function of time in the weightlessness environment. The mission will involve 60 to 90 days in orbit and subsequent recovery of the monkeys and the complete urinary and fecal output.

The monkeys' body will be restrained; his legs, arms, and head will be free. Various catheters will be implanted to collect urine and blood samples. Feces samples will also be collected.

The cardio-vascular portion of the experiment requires continuous measurement of heart rate and blood pressure as well as a cardiac output measurement every few hours. This latter measurement involves the injection of a tracer into the blood system and monitoring its dispersion. The technique is a standard laboratory procedure when a die solution is injected.

The metabolic studies involve detailed monitoring of all energy and substance interchange between the monkey and his environment. Each monkey is to be placed in an adiabatic bomb to measure his heat production. Oxygen consumption will be quantitatively measured as will the CO_2 and H_2O production. The entire urinary output will be collected; each batch consisting of three hours output will be frozen and stored. The fecal output will similarly be collected, identified, and frozen for storage. In addition the liquid and food input will be monitored.

At the completion of the mission, the monkeys, the urinary output, the fecal output, and any contaminant absorption beds will be returned to earth.

Various components of this experiment have been performed in the laboratory; the complete experiment has not been performed simultaneously on a single animal. Measurement techniques applicable to space flights are being developed. The investigating team contemplates experiment flight during 1973.

System modification. - The basic OPS life support system for the weightlessness experiment does not provide metabolic isolation of the two primates. Two metabolically isolated chambers can be provided in the OPS with minor modifications using the same life support equipment components proposed for the weightlessness experiment. The necessary modifications would be as follows:

(1) A wall would be placed across the pressure vessel to provide atmosphere and thermal isolation between the two primate chambers.

(2) Two sets of fans, heat exchangers, LiOH cannisters and atmosphere control units would be installed in the spacecraft to provide isolated atmosphere control systems. With the exception of the fans and LiOH cannister which would be scaled down in size, this equipment would be identical to the

equipment presently proposed for the OPS spacecraft. The system so modified would provide for close monitoring of oxygen usage, CO_2 output and heat output of each animal individually. Monitoring of the oxygen consumption and CO_2 concentration is inherent in the basic OPS design.

(3) The waste management filters would be modified to comply with the collection requirements of the new experiment. Since the animals for the proposed experiment are equipped with catheters and fecal collectors, the proposed filters of the OPS system would be replaced with a more compact, simple filter in series with the circulating atmosphere. Provisions for collecting and freezing fecal and urine materials would be added to the waste management system.

(4) The containers for storing O_2 and N_2 would be unmodified with the exception that a second set of control valves would be added to the output manifold. The presently proposed system has provisions for accurately monitoring the usage rates of O_2 and N_2. These usage rates in conjunction with the known leak rates, monitoring of CO_2 and water outputs will provide an accurate measurement of the animal's usage of oxygen.

(5) Asecond gas analyzer would be added to provide independent monitoring of both isolated chambers.

A preliminary analysis of the increase in data, command, and power requirements associated with the dual life support system would not change the design of the support subsystems.

The addition of the extra fans, heat exchangers, LiOH cannisters and atmosphere controls are well within the envelope constraints of the OPS.

The thermal control subsystem would require only minor preliminary changes to include a second set of heat exchangers.

Table 8 summarizes the experiment and briefly describes its effect on the basic OPS design.

Neurological Bio-A Experiment
Principal Investigator - W. R. Adey, M.D.
University of California at Los Angeles

Experiment description. - The experiment measures the neurological response of two chimpanzees as a function of time in the weightlessness environment.

The experiment consists of flying two young chimpanzees (25-40 pounds) in their own individual life support system for a flight of 60 to 120 days.

One of the chimpanzees will be unrestrained in a spherical cage which has an internal diameter of about five feet. The other chimpanzee will be restrained on a movable couch; the cage will be a four foot sphere truncated in a region which is out of the monkey's view.

TABLE 8. - AUTOMATED PRIMATE RESEARCH LABORATORY (DR. N. PACE, UNIV. OF CALIFORNIA, BERKELEY)

Objective: Measure cardio-vascular and general metabolic response of two restrained Pig-Tailed monkeys (Macaca nemestrina) as a function of time in the weightless environment.

Development Status: Quantities to be measured are defined; techniques of measuring monkey characteristics being proved; methods for monitoring metabolic effects on environment being designed. Operation of system and proof that all measurements may be made simultaneously on one monkey required.

Experiment Characteristics:	Effect on Spacecraft Design
Size: Undefined specifically, but within envelope of existing OPS.	1. Separate life support systems for each monkey.
Weight: Undefined specifically, but within capability of existing OPS.	2. Modify existing waste control system.
Power: Undefined.	3. Additional equipment to collect, freeze, and store all fecal & urinary output.
Data Requirements:	4. Provide waste material EVA canister and means for getting wastes into it.
Continuous monitoring of heart rate, blood pressure, O_2 consumption, H_2O, CO_2 and heat production.	5. Provide each monkey with adiabatic chamber.
Periodic measurement of cardiac output.	6. Provide separate water removal equipment for each monkey.
Control Requirements: Initiate cardiac output measurements similar to existing OPS requirements.	7. Provide quantitative measures of heat output of each monkey as well as O_2 consumption and H_2O and CO_2 production.
Operational Requirements: 60-90 day orbit.	8. Increase electrical power capability.
Recovery of monkeys and all fecal & urinary output.	

Both chimps will be presented tasks of varying complexity; the complexity will be governed by an onboard computer which evaluates the chimp's performance. The tasks will involve pushing buttons in response to cues given by lights. The buttons and lights will be uniformly distributed around the inside of both cages. The restrained monkey will have a joy stick control on his couch to enable him to move the couch and thus reach the various buttons.

The current air circulation is envisaged as a series of switched ducts so that the air flow, 80 ft/min, could be changed within the capsule and thus avoid an air flow reference.

Each chimp will contain numerous implanted sensors to monitor brain potentials, eye position, neck muscle status, trunk status, galvanic skin response, temporatures throughout the system, and very likely ultrasonic blood flow meters. The maximum band width of any one channel is 100 Hz. The total band width for all channels for one chimpanzee is between 4 and 5 megahertz for the PCM data. These measurements are sufficient to enable the Principal Investigator to deduce the position of the chimp's body and even where he is looking. The gap between data acquisitions should be less than four hours.

The waste management is considered the greatest problem. The fecal and urinary output of the restrained chimp will be collected. The feces will be stored for recovery; the urine will be collected in batches which will contain all the urine produced in a 3 to 4 hour period. The urine will either be frozen and stored or preferably analyzed in flight and dumped. A proprietary technique not involving catheters has been developed to collect these wastes. The waste management for the unrestrained chimp is the current main concern. The final system will probably involve a mechanical scraping action to remove caked feces and an air purge to remove loose material. The air ports must also be cleaned.

The various primate investigators have decided that a liquid diet should be used for flight experiments. Reasons for this decision include the greater reliability of liquid food dispensers (as contrasted to pellet dispensers), and the problems of pellet stability. However, it may not be possible to implement this decision because of the high viscosity of the liquid which has enough caloric value to balance both the food and water requirements of the chimps.

The electrical power requirements of the experiment are not well defined. It appears that 0.7 to 1.0 K watt will be required for the inplant telemetry and task performance requirements. The waste management and environmental support requirements appear to be additional. Spacecraft to ground telemetry is definitely additional.

The Environmental Control System will need to monitor the CO_2 production of each chimp continuously; each breath would be desirable but a 30 second response time sensor in the air flow would be satisfactory. The current thought is to use an infrared sensor. A thermal balance for each animal is desirable.

A different waste management technique will be required; however, the Principal Investigator is developing this and no spacecraft problems are foreseen.

Table 9 summarizes the experiment and briefly describes its effect on the basic OPS design.

The internal lighting will initially be set on a 24 hour cycle with 12 hours of high intensity light and 12 hours of dim light. Later in the mission the repeat cycle will be increased above 24 hours and then decreased to less than 24 hours. Finally the chimps will be allowed to set their own time rythms. The ratio of maximum to minimum illumination should be at least 10:1 for the chimps' comfort. It has been discovered that the chimp feels it is dark if the spectral range is decreased from the whole visible spectrum to a 0.69 to 0.75 micron spectral range and the total illumination is only decreased by 30%. Using this technique, the chimp experiences night-day sequences and television cameras can operate continuously without shutter changes.

It is imperative that both chimps fly in the same spacecraft. The maximum accelerations experienced should be less than 10^{-3}g.

The experimenter feels that it would be desirable to have an astronaut check the equipment operations daily although no chimp-astronaut interaction is desired.

System modification. - Adaptation of the OPS to this experiment requires a modification of the life support system and a change in size of the living quarters. The chimpanzee chambers are approximately spheres with four and five foot diameters.

It is necessary to have separate life support systems for each animal to satisfy the metabolic requirements. The required modifications to the OPF life support would be similar to those described in the previous Section. The food, water, and oxygen requirements of the chimpanzees for 120 days are comparable to those provided by the OPS for a smaller animal for a year. The carbon dioxide requirements are also comparable. The quantities are comparable for both missions, with higher rates for the UCLA experiment.

Reproductive Bio-A Experiment
Principal Investigator - J. P. Meehan, M.D.
University of Southern California

Experiment description. - The experiment objective is to observe behavior of mature primates in a weightless environment and to produce young who were conceived and born in this environment.

The experiment is in the initial conception stage now. However the gross properties are similar to those of the experiment for which the OPS was designed.

TABLE 9. - NEUROLOGICAL BIO-A EXPERIMENT (W. R. ADEY, M. D., UNIVERSITY OF CALIF., LOS ANGELES)

<u>Objective</u>: Measure the neurological response of two chimpanzees as a function of time in the weightless environment.

<u>Development Status</u>: Quantities to be measured are defined: The operational techniques for the emplanted transducers and the waste control system are being designed.

Experiment Characteristics:	Effect on Spacecraft Design:
Size: 62" OD x 108" Weight: Undefined Power: 700 w (Dr. Adey's estimate) + life support.	1. Separate life support systems for each monkey. 2. Increase size of animal chambers by a factor of three.
Data Requirements: 10 MHz PCM	3. Modify existing waste control system. 4. Additional equipment to collect, measure, freeze, and store or dum all fecal & urinary output.
Control Requirements: Override pre-programmed control.	5. Provide waste material EVA conister and means for getting waste into it.
Operational Requirement: 60-120 day orbit.	6. Provide separate water removal equipment for each chimpanzee.
Recovery of chimpanzees and fecal material.	7. Provide quantitative measures of heat output of each chimpanzee as well as O_2 consumption and H_20 and CO_2 production. 8. Increase electrical power capability.

Two sexually mature primates weighing 15 to 20 pounds will be flown and observed for a year. The primate species has not been selected. A common cage will be used for both animals, they will be observed periodically by television and will be presented tasks similar to those given to the OPS primates.

There will be a four channel implanted telemetry system in each animal; the bandwidth for each channel is 35 Hz.

System modification. - The modifications of the existing OPS spacecraft are minimal and consist of slightly enlarging the oxygen and nitrogen storage capacity as well as removing the dividing portion of the existing cages to make one large cage. It will be necessary to insure that the primates can be recovered with the existing technique. The investigator desires a measure of the CO_2 production of the animals.

Table 10 summarizes the experiment and briefly describes its effect on the basic OPS design.

Long Term Adaptation to a Weightless Environment
Principal Investigator - J. P. Meehan, M.D.
University of Southern California

Experiment description. - The experiment will observe the growth and habits of mice bred and raised in a weightless environment.

The experiment objective is to orbit a colony of mice, initially four, which then live, breed, and raise their young in a weightless environment. It is expected that there will be sixteen mice in the colony at the end of the year in orbit; the mice are to be recovered. A nesting area will be provided in the center of the cage unit; food and water are provided around the periphery of the cage. The experiment consists of watching the behavior, via television, of the mice and visually monitoring the growth of the young.

A laboratory test model of this experiment has demonstrated the feasibility of the experiment and its associated hardware. Flight equipment is currently being designed. A description of the laboratory test model is given in "A Program For the Study of Long Term Adaptation to a Weightless Environment Providing Three Dimensional Freedom of Movement" which was presented at NASA-Ames Research Center in late 1966 or early 1967.

The laboratory test model is 15 inches in diameter, 60 inches long and weighs 500 lbs. Obviously the flight model will be smaller and lighter.

System modification. - This experiment as currently designed is completely self contained. By adapting the experiment to the OPS system, the experiment could be decreased to 150 pounds in a chamber 15 inches in diameter x 30 inches long. This will readily fit the OPS as a companion to the primary primate weightlessness experiment.

Table 11 summarizes the experiment and briefly describes its effects on the basic OPF design.

TABLE 10. - REPRODUCTIVE BIO-A EXPERIMENT (J. P. MEEHAN, M. D., UNIVERSITY OF SOUTHERN CALIFORNIA)

<u>Objective</u>: To observe behavior of mature primates in a weightless enviroment and to produce young who were conceived and born in this environment.

<u>Development Status</u>: Conceptual Only - No problems foreseen.

<u>Experimental Characteristics</u>:

Undefined, within capabilities of OPS.

<u>Date Requirements</u>:

Television, 1 x 10^6 bps - 38 minutes a day plus a 280 Hz bandwidth channel.

<u>Control Requirements</u>:

Initiate observations.

<u>Operational Requirements</u>:

1 year minimum orbit.

Recover animals.

<u>Effect on Spacecraft Design</u>:

1. Enlarge Oxygen, nitrogen storage.
2. Enlarge Li OH storage.
3. Remove center partition in cages.
4. Insure recovery of the original primates and any offspring.
5. Add additional CO_2 sampling points to monitor production rate.

TABLE 11. - LONG TERM ADAPTATION TO A WEIGHTLESS ENVIRONMENT (J. P. MEEHAN, M. D., UNIV. OF SO. CALIF.)

Objective: Observe the growth and habits of mice bred and raised in a weightless environment.

Development Status: Laboratory test model constructed and verified. Flight equipment being designed.

Experiment Characteristics
(Modified for OPS)

Size: 15 in. OD x 30 inches long
Weight: 150 lb
Power: 100 w

Data Requirements:

1×10^6 bps - 38 minutes day

Control Requirements:

Initiate television viewing

Operational Requirements:

1 year in orbit

Recover mouse colony

Effect on Spacecraft Design

1. Allow simplification of all life support equipment.
2. Allow decrease in size of pressure canister.

Summary

Table 12 presents an overall summary of the capability of the basic Orbiting Primate Spacecraft and the type of modifications required to support the biological experiments discussed in this section.

The OPS design provides life support, waste management, and recovery capabilities for two small primates for a one year mission. These same systems can support smaller animals for proportionately longer priods and larger animals for shorter periods. In an emergency, the life support could even support man for a short period. An increase in versatility is achieved if the life support system is slightly modified so that quantitative measurements of metabolic functions can be achieved. Several experiments require separate quantitative life support and metabolic measurements on several animals; this capability is also desirable. The actual animal life-cell will vary depending upon the animal size and the experimental objectives; however, these changes need not change the external envelope of the spacecraft.

TABLE 12. - MATRIX SHOWING ADAPTABILITY OF OPS TO VARIOUS EXPERIMENTS

Experiment \ Subsystem or Equipment	Environmental Control	Waste Management	Life Cell	Thermal Control	Structure and Mechanical	Docking	Recovery	Instrumentation	Telemetry	Command and Control	Power and Cabling	Attitude Control
Automated Primate Research Laboratory Dr. Pace - UCB	S	M	S	S	OK	OK	S	M	OK	S	OK	OK
Neurological Bio-A Dr. Adey - UCLA	S	M	M	S	OK	OK	S	M	OK	S	M	OK
Reproductive Bio-A Dr. Meehan - USC	OK	OK	S	OK	OK	OK	S	OK	OK	S	OK	OK
Long Term Adaptation to a Weightless Environment* Dr. Meehan - USC	OK	*	*	OK	OK	OK	S	S	OK	S	OK	OK

Code
- E - Eliminate
- OK - Use Existing
- S - Slight Modification
- M - Major Modification
- * - Can be carried along with basic OPS experiment

APPLICATIONS WITH S/AAP ORBITING LABORATORY

Conceptual approaches have been developed for extending the utilization and effectiveness of the Orbiting Primate Spacecraft as its subsystems by integration with the S/AAP Orbiting Laboratory. The basis for these studies, the analytical processes, and the selected candidate configurations are described here.

Objectives

This study was initiated to examine the versatility of the Orbiting Primate Spacecraft and the extent to which it was directly applicable to alternate mission modes. The study included:

(1) Consideration of the Orbiting Primate Spacecraft as an extended addition to an orbiting laboratory.

(2) Examination of a Modular Orbiting Primate Spacecraft as an addition to an orbiting laboratory.

(3) Utilization of Orbiting Primate Spacecraft subsystems in support of the orbiting laboratory.

The Orbiting Primate Spacecraft as described in the introduction to this volume and the Orbiting Laboratory described in the following section were the baseline configurations for this study.

Orbiting Laboratory Description

The SIVB stage's hydrogen tank is being modified to convert its 10,000 cubic foot volume into living and working quarters for long duration habitation in space. The modified stage used in conjunction with two additional modules, an airlock and a docking adapter, as shown in Figure 13, provides an orbital workshop for performing various experiments. The airlock permits astronaut movement from their spacecraft to the SIVB stage without depressurizing either the spacecraft or the SIVB. The docking adapter is attached to the airlock and provides a means of joining together up to five payloads. These modules, together with an Orbiting Primate Spacecraft attached to the docking adapter, as shown in figure 14 would comprise an Apollo Application cluster.

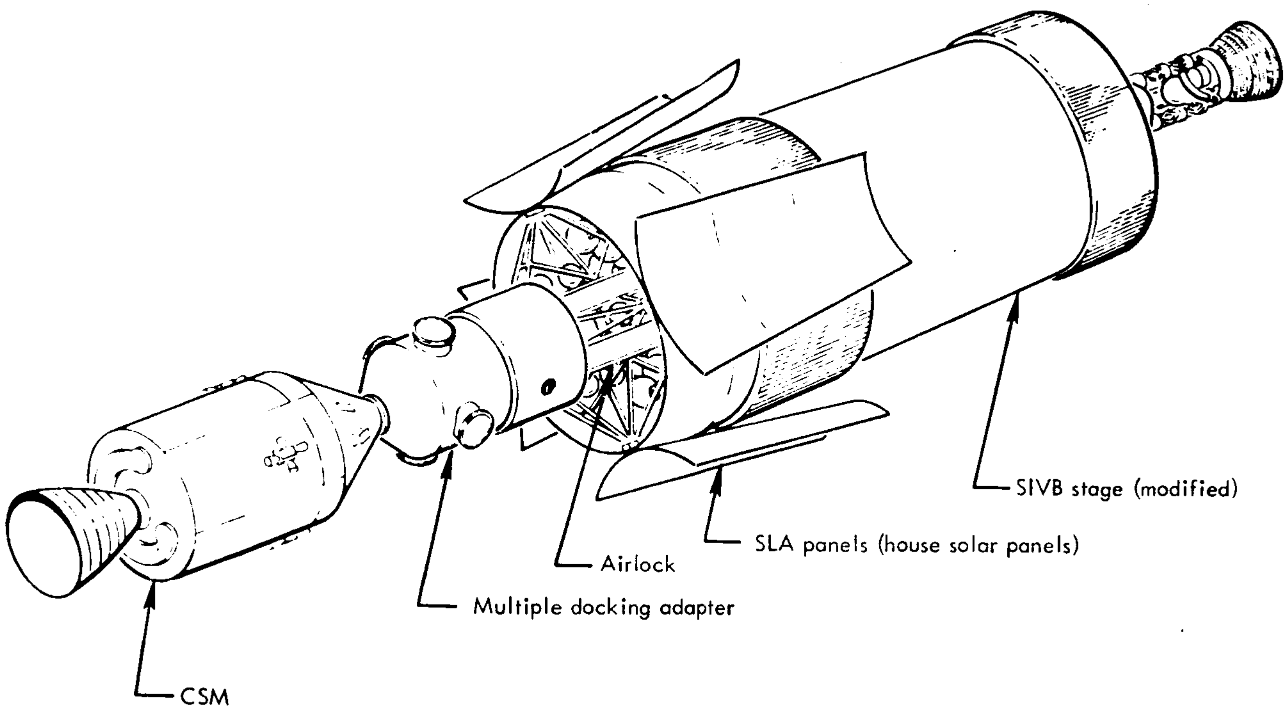

Figure 13. - Orbital workshop (April 1967 SLA panels attached)

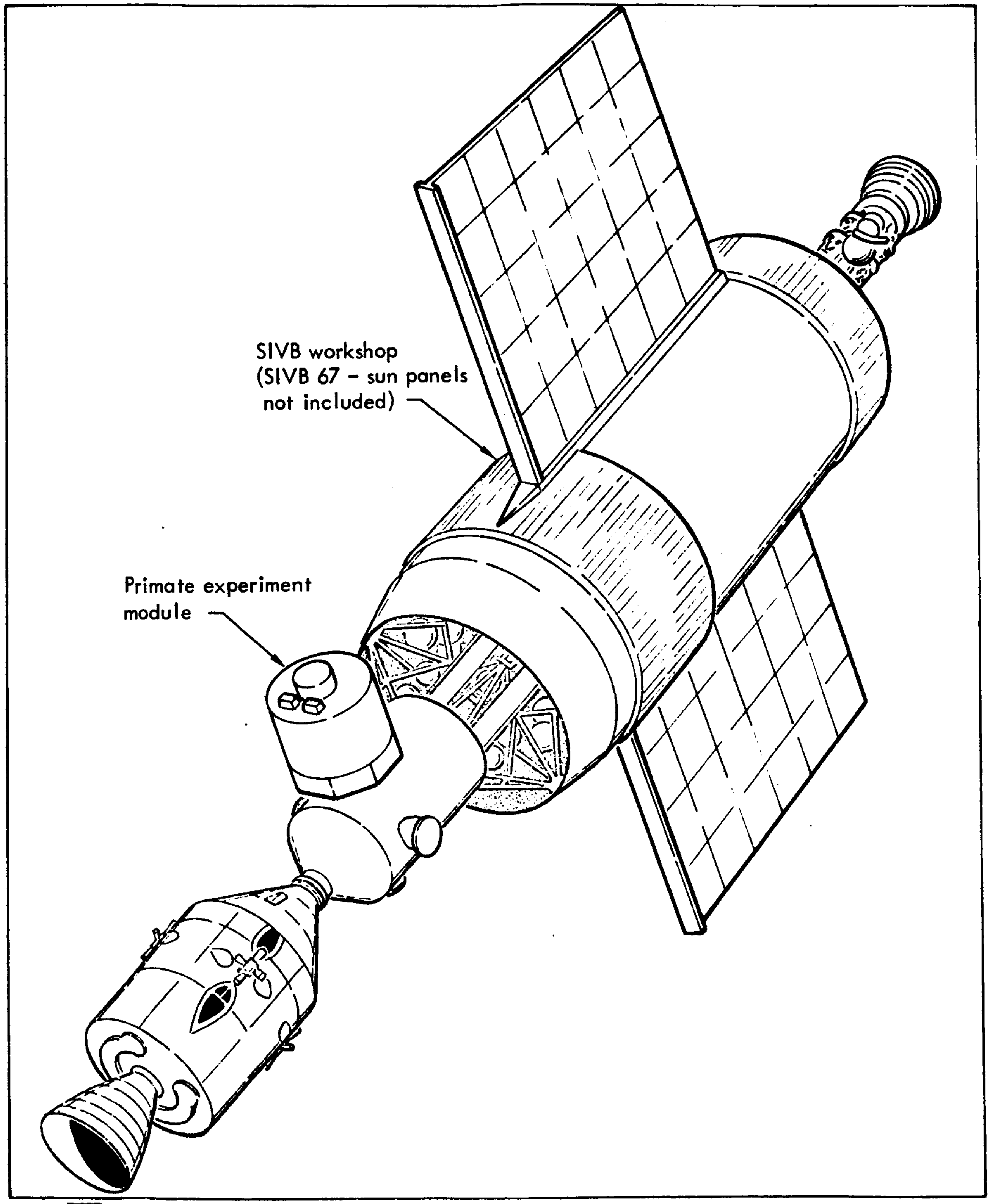

Figure 14. - Orbital workshop with primate module attached (cluster A less all payloads except primate module)

Orbital workshop. - A flight configuration Saturn SIVB stage, with some modification, will be used for the orbital workshop; additional equipment includes an Airlock Module (AM) and a Multiple Docking Adapter (MDA). The airlock is mounted on the forward end of the launch vehicle at the lunar module attach points. The Multiple Docking Adapter is rigidly mounted to the forward end of the Airlock Module. Figures 15 and 16 further illustrate the system. Figure 17 depicts the ascent configuration and Figure 18 shows the general gas flow of the launch environmental control and inerting system. A general weight and performance summary is given in Table 13.

SIVB workshop. - The hydrogen tank of the stage is a 10,000 cubic foot volume which will be converted into a shirtsleeve zero-gravity two-story laboratory or workshop. The main floor is devoted to living quarters for the crew and a laboratory and maintenance area which will be equipped to carry out various experiments and maintenance functions. Special experiments will be conducted in the remainder of the volume. The stage is being modified so that the crew may quickly convert the tank to the workshop. These modifications include a 40-inch diameter, quick-opening hatch in the forward end of the tank, a rigid floor over the common bulkhead, crew quarters partitions and curtains, and astronaut aids such as nets, handles and padding.

The pre-installed floor is expected to be metal mesh so that the flow of propellant during the launch will not be hindered. There will also be fittings to which partition segments will be attached to make individual compartments for crew quarters, exercise areas, a food preparation and storage room, a hygiene and waste management room, a biomedical monitoring area, and a very large volume for zero-gravity type experiments.

Airlock module (AM). - The airlock module is located at the forward end of the SIVB stage within the instrument unit and the spacecraft lunar adapter structure and is attached to the vehicle at the lunar module attach points. The forward end of the airlock module will be rigidly attached to a multiple docking adapter (MDA).

The airlock module has a 48-50 inch effective diameter tunnel extending from the MDA to the workshop and is supported by four truss assemblies. Components of the life support system and other systems are mounted on the airlock structure.

A two gas (oxygen-nitrogen) life support system being planned for the workshop will be carried on the airlock module. Breathing gases for the initial AAP 1 & 2 flights will be carried in the airlock's tanks and the system resupplied for future revisits.

Electrical power for the workshop and command module operations will be provided by three systems: fuel cells in the service module (SM), batteries in the airlock, and a large array of solar cells. Supplementary liquid oxygen and liquid hydrogen for the service module (SM) fuel cells is also carried on the airlock module (AM).

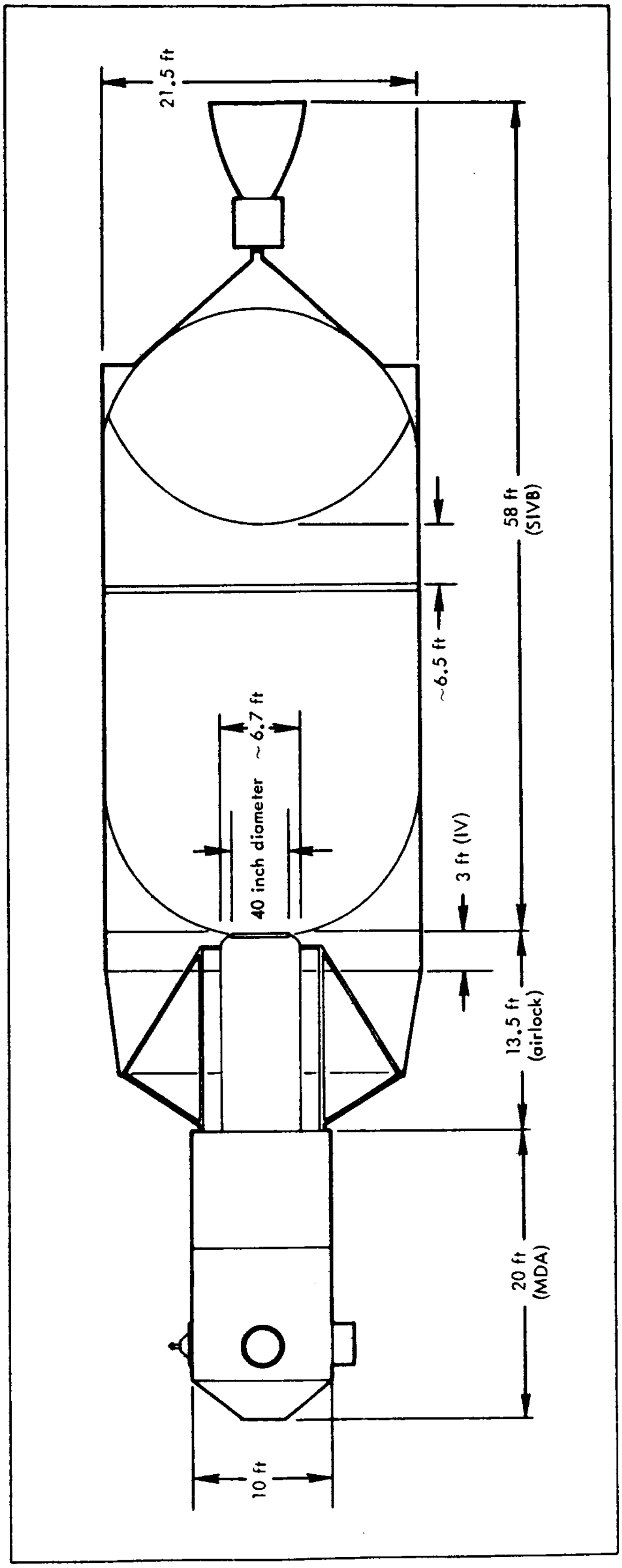

Figure 15. - Orbital workshop

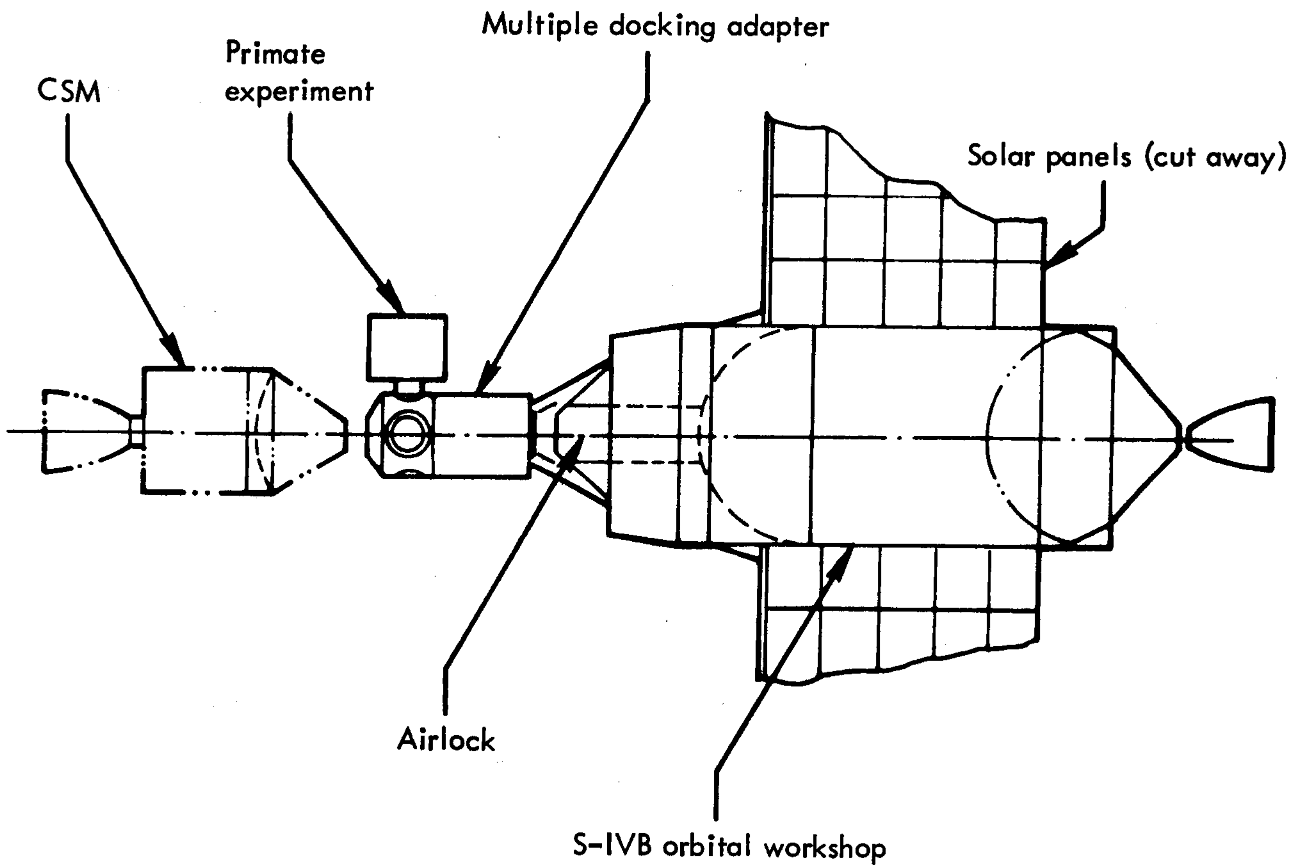

Figure 16. - Orbital workshop with CSM, primate experiment, and MDA

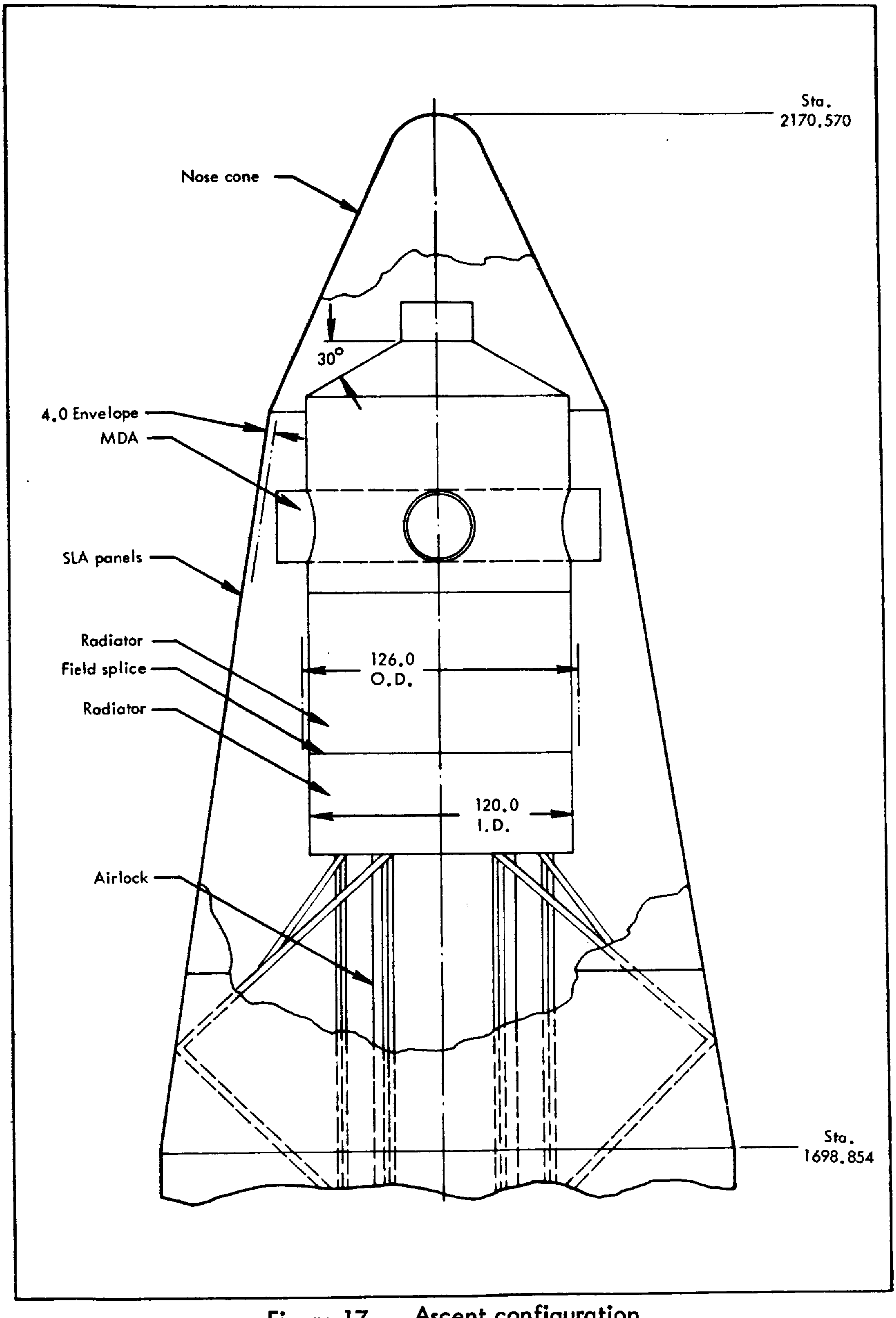

Figure 17. - Ascent configuration

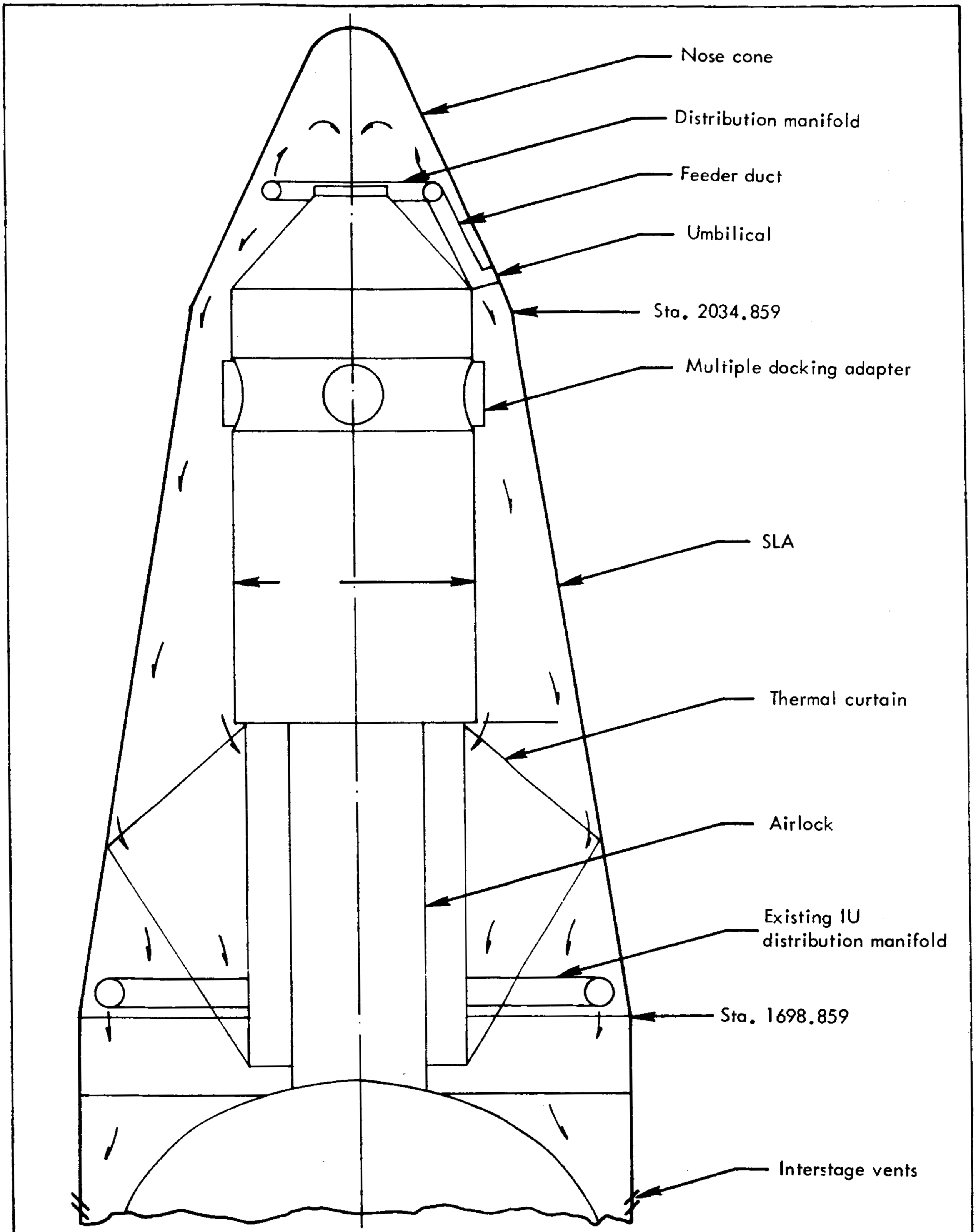

Figure 18. - Environmental control and inerting system

TABLE 13. - EXAMPLE WEIGHT AND PERFORMANCE SUMMARY

Launch Vehicle	AAP-2
Injection Orbit (n.mi.)	260 cir.
Payload Capability (lb)	27,900
Payload Weights (lb)	
SLA	4,100
Nose Cone	1,067
MDA	3,595
Airlock Module	8,460
Solar Electrical System	4,100
Experiments	1,927
L/V Mods.	2,384
TOTAL PAYLOAD WEIGHT (lb)	25,633
Payload Margin	2,267
Launch Capability	27,900

Multiple docking adapter (MDA). - The Multiple Docking Adapter (MDA) is installed on the forward end of the airlock module and has provisions for docking five payloads is shown in Figure 15; a longitudinal drogue docking position located on the forward end of the MDA, and four radial positions, three with drogues and one with a probe. The probe position accommodates the LM/ATM; the drogue positions are for CM type dockings.

The docking adapter has a center section 120 inches in diameter and seven feet long with four 34-inch diameter tunnels located 90 degrees apart about this center tube. Each tunnel is about 20 inches long and contains CM and lunar module docking elements and an Apollo sealing hatch.

SIVB passivation and activation. - The Saturn SIVB stage arrives in orbit with some residual propellants, an active range safety system and with other potential hazards to astronaut safety. Prior to the CSM docking to the spent stage, the range safety system will be deactivated by ground command and sequential venting of propellant residuals will be started by a preprogrammed, tape-operated sequencer in the Instrument Unit (IU); the liquid oxygen tank will be vented first followed by the hydrogen tank. Other venting processes initiated by the Instrument Unit (IU) sequencer include venting of the cold helium spheres, venting of the J-2 engine start bottle and venting of the J-2 engine control sphere. A passivation control panel will be located in the airlock module. This panel contains the controls the astronauts will use to vent the auxiliary propulsion pressurant supply, Instrument Unit air bearing supply and the SIVB control helium spheres. Monitoring of systems being vented will be accomplished by the astronauts and by telemetry with ground voice confirmation to the astronauts.

After all the potential hazards have been eliminated, the astronauts will begin tasks required to make the liquid hydrogen tank a habitable workshop. Activation procedures are planned to provide maximum safety, economy of effort, minimum tools and minimum time for the astronauts. Many of the features required for habitability such as flooring, mobility aids, thermal sleeves, fire retardative coating, various mounting and stowage provisions, and protective padding, will be installed in the tank prior to launch.

The spent stage will also be outfitted with the necessary equipment to allow it to be stored in orbit for periods up to six months and then be revisited and reactivated for two to six month staytimes. The hydrogen tank, the airlock and Multiple Docking Adapter (unoccupied cluster) will be stored unpressurized in orbit.

Additional payloads. - Other payloads may be installed on the cluster either in addition to or in lieu of, the LM/ATM. The primate experiment is one such payload and may be envisioned as a module docked to the cluster (Figure 14) or as an experiment payload carried as a part of the cluster's "built-in" complement. The following section discusses the utilization of the cluster as an orbital "base" for the primate experiment.

Primate Experiment Orbital Laboratory

Integration of the primate experiment with the Orbital Laboratory concept previously described was studied to develop alternate mission modes for the Orbiting Primate Spacecraft System. Requirements and constraints were defined and alternative approaches studied to arrive at selected mission mode in which the cluster is utilized as an orbital "base".

Requirements and constraints. - The following requirements and constraints were limited to overall configuration and interface items.

(1) General:

(a) The primate experiment shall not impose any hazards to the crew or mission beyond those normally experienced in orbital operations. For example, the potentials for introducing contaminants into the crews environment, for presenting fire or blast hazards, or for imposing excessive demands or constraints on crew time, vehicle attitude, or logistics operations, shall be minimized.

(b) The primate experiment shall be compatible with the cluster imposed experiment requirements, guidelines, and constraints.

(2) Orbiting Primate Spacecraft (OPS). The OPS is defined here as a self-contained, or semi-self-contained, unit, orbited by a launch separate from the workshop and added to the cluster as a "modular" element of the system.

(a) The OPS shall be entirely capable of self support during the period from launch to achievement of operational status as a part of the cluster. This includes such features as attitude control power, and data link.

(b) Spacecraft antenna geometry shall be compatible with command and data link operation when the spacecraft is attached to the cluster and when the spacecraft is operating unattached (eg., prior to docking).

(c) The OPS shall be compatible with the cluster's solar orientation constraints.

(d) The OPS shall utilize the Apollo docking system at the OPS/MDA interface.

(e) The OPS shall be capable of being jettisoned in an emergency.

(f) The OPS shall be provided with EVA aids such as hand rails, hand holds, etc.

(3) Primate Experiment Subsystems

(a) Wet Workshop (launched as an active booster stage). Equipment installed in the H_2 tank during launch must be compatible with liquid hydrogen. Equipment requiring access should be designed for stowage external to the tankage and should be of the modular "plug-in" type to reduce crew time required for erection. Particular care shall be taken to minimize the probability of introducing contaminants into the crew compartment.

(b) Dry Workshop (launched with experimental equipment, life support, etc., installed and checked out). Equipment shall employ a modular design, to the extent practical, for all items for which remove and replace operations may be expected. Particular care shall be taken to minimize the probability of introducing comtaminants into the crew compartment.

Alternate approches. - There are a large number of alternate approaches for integrating the primate experiment into the orbiting workshop complex. These include the degree of experiment modularity, location of the experiment in the workshop, methods of installation (eg., as a single module or in multiple units, or internal versus external installations), and others. The following discussion considers potential candidate alternative on a gross scale and makes one of the concept selection chart in illustrating the rationale for reducing the large number of possibilities by excluding, by judgement, the less desirable or impractical possibilities. This methodology involves constructing matrices of candidates and then reducing the number of possibilities (the product of the rows and columns) by recording the judgements used to exclude either rows, columns, or particular intersections. Numbers in the column/row intersections refer to the numbered comments or discussion in the text.

Overall installation: Ten general groups of alternative approaches may be identified for the integration of the primate experiment in the orbital cluster; these are given in Figure 19. These alternatives can be reduced in number by the following judgements;

(1) The utilization of the workshop as a "dry" payload has a small probability of occurance at present. General ground rules for the workshop are that ground-installed equipment must not interfere with the stage's primary flight function.

(2) Requirements for compatibility with liquid hydrogen and for mission safety precludes the efficient installation of the primates in the workshop during launch.

(3) Requirements for access to the primates are particularly difficult to meet if the cages are installed within the wet tank prior to launch.

Experiment Configuration \ Workshop Configuration		Wet Launch Workshop is an active launch vehicle stage	Dry Launch Workshop is a Payload only
Primate Experiment is a cluster module	External to Workshop	Feasible	1.
	Within the workshop	2. 3.	1.
Primate Experiment is installed in subsystem modules	External to the workshop	Feasible	1.
	Within the workshop only	2.	1.
	External and within the workshop	Feasible	1.

Figure 19. - General alternative approaches

The three alternatives which will be further considered for this study are therefore: (1) a single external module, (2) subsystems located both within and outside of the workshop, and (3) subsystems located external to the workshop. These alternatives are schematically illustrated in Figure 20.

Docking alternatives (single external module): The docking event is one of the most significant in establishing the single external module design. Alternatives include docking collar alternatives, docking collar installation alternatives, docked attitude alternatives, and docking maneuver alternatives.

Docking collar alternatives: Docking collar (i.e. the structure and mechanism for incorporating the Apollo docking system) alternative, compared in Figure 21 include:

Docking collars which are fixed in the OPS structure.

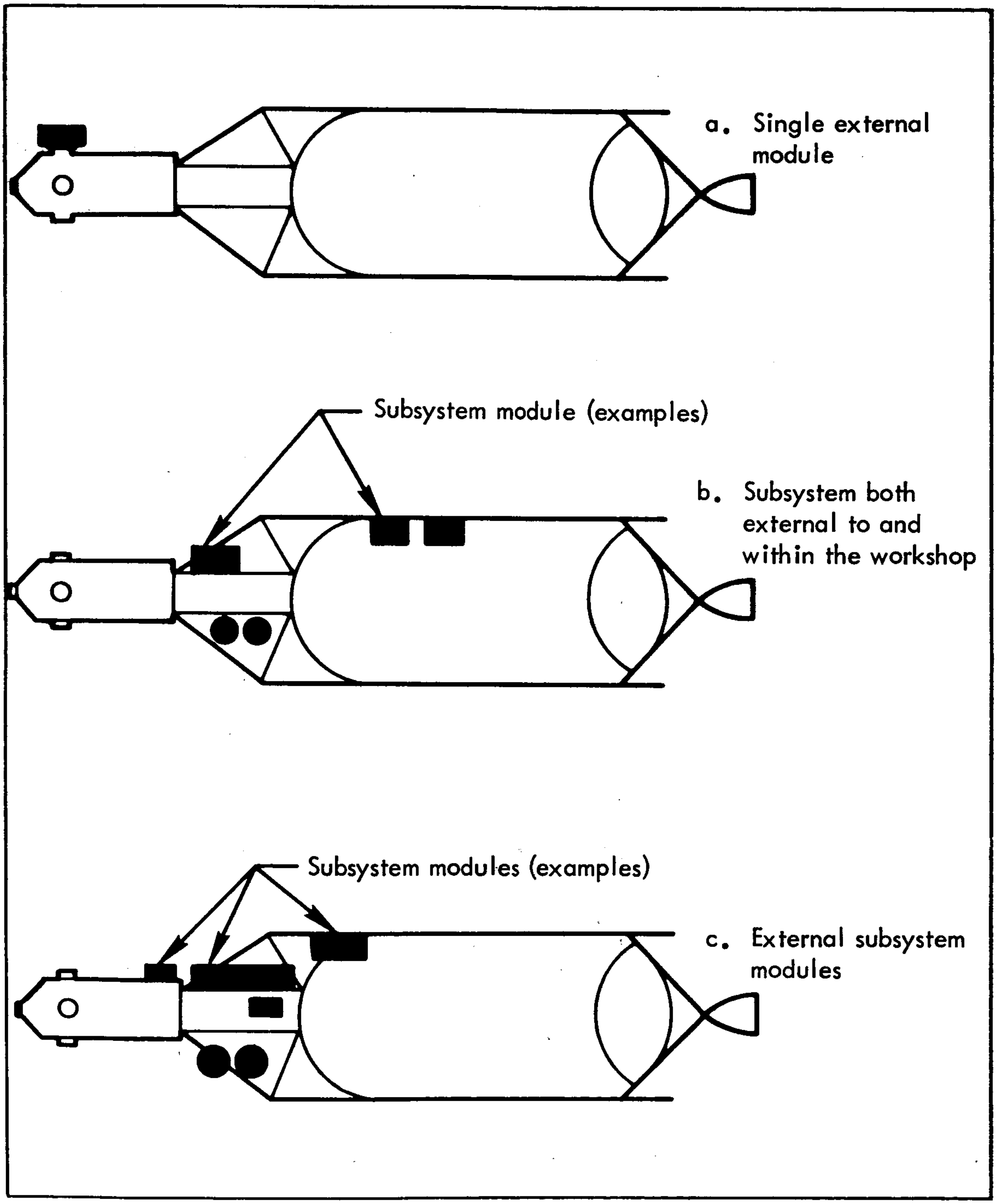

Figure 20. - Alternative installation approaches

Docking collars which are movable and may be used to reposition the OPS after docking.

Use of the "existing" collar for the "Tug" vehicle.

Use of an alternate collar for the "Tug" vehicle. These four alternatives are briefly examined in Figure 21.

Fixed collars are, of course, to be preferred over the movable collars due to such considerations as complexity, weight, and power. Additional fixed docking collars will lead to increases in system weight, and for side mounted or asymetrical installations, require considerable structural changes as well. A central location on the - X axis where the LiOH can is presently installed is the most convenient location relative to the existing design, for installing an additional collar. The structure was designed for this contingency.

Tug Position \ Additional Collar Installation	No Added Collars	Fixed Docking Collars	Movable Docking Collars
None	Feasible a	(2)	(1)
Use of existing Collar	Feasible b	Feasible c	(3)
Use of an Alternate Collar		Feasible d	(4)

Figure 21. - Docking collar alternatives

With a moveable collar, the spacecraft can be positioned to the best advantage for docking relative to visibility and docking dynamics; and can be repositioned after docking; however, this alternative can carry significant performance penalties.

Use of the existing collar for the tug vehicle probably requires the least modifications to the primate module and to the cluster since it is presently designed for this function. A second collar or a self-docking-to-the-cluster capability is required in addition however.

Alternate collars for the tug permit docking the primate module to the cluster at the present docking collar interface. This interface contains a docking drogue and therefore either requires a "probe" position on the cluster or a modification to the primate module to replace the drogue with a probe. Since the present docking interface is used by the CSM to extract the payload from launch vehicle, this alternative would (a) require replacing the drogue with a probe after extracting the CSM and utilize an EVA mission, (b) require a change to the CSM docking system (unlikely), or (c) require a self-separation system (probably required for use in the Titan or Centaur vehicles).

The eight possibilities indicated in Figure 21 can therefore be reduced to four by the following judgements:

(1) This alternative is probably too complex for consideration here and would be to re-position the module on the cluster and require a self docking capability.

(2) The present collar can be used with self docking. Additional collars not needed.

(3) Use of the existing collar for the Tug, together with a movable collar is a potential requirement due to visibility restrictions during docking, but is a complexity to be avoided if possible. For good direct vision during docking an asymetrical condition for the closing velocity vector and the centers of mass is indicated, yielding large bending loads at the docking interface.

(4) Use of a movable collar for the Tug has disadvantages similar to (3) above.

The remaining alternatives to be considered are:

a. Use of the present docking collar together with a rendezvous and dock-capability.

b. Use of the present docking collar together with a self docking capability only; rendezvous by tug.

c. Use of existing collars for the tug and added collars for the cluster interface.

d. Use of an additional collar for the tug.

These are illustrated in Figure 22.

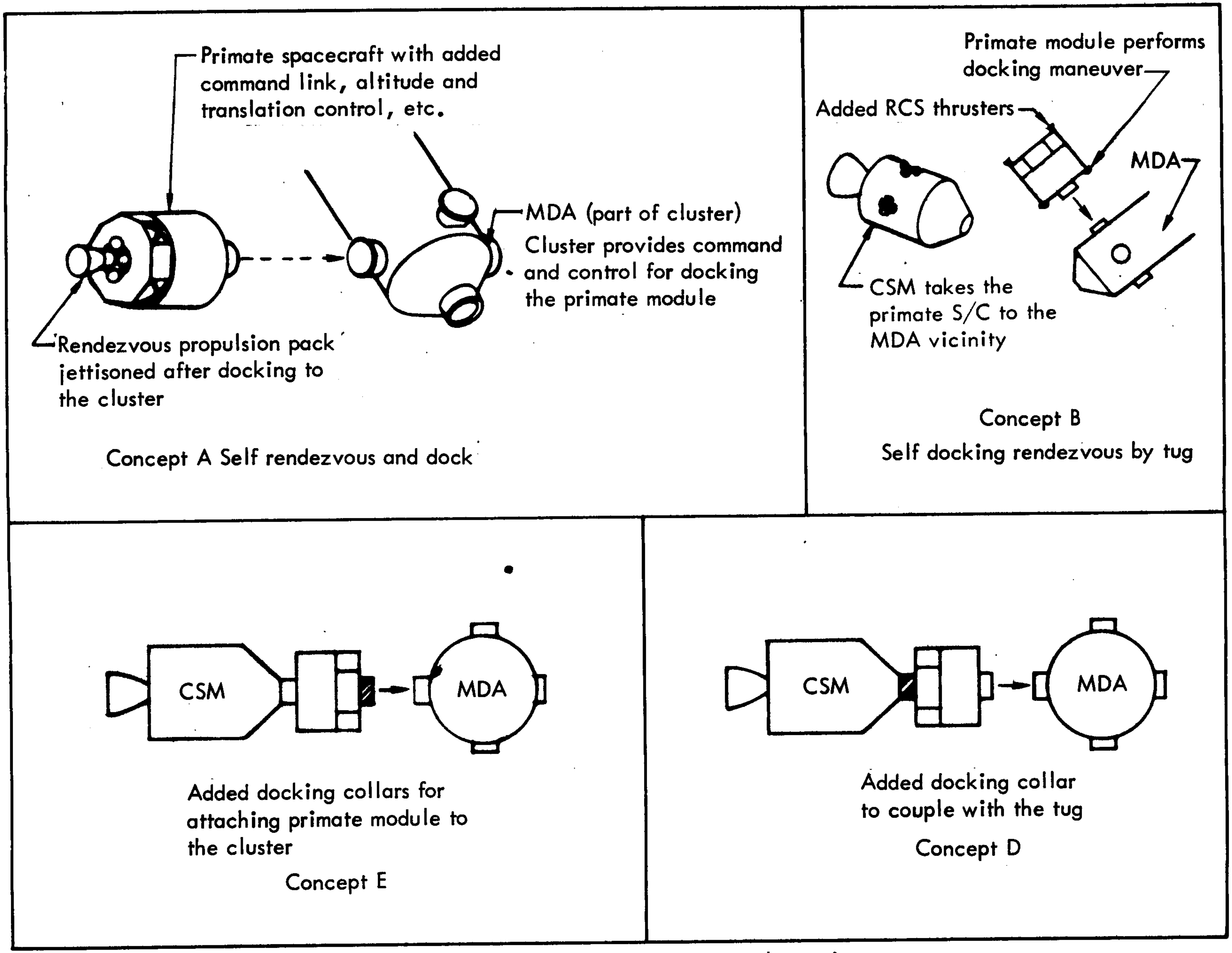

Figure 22. - Rendezvous and docking alternatives

Docking collar installation alternatives: In considering the addition of another fixed docking collar (moveable collars were shown less attractive in the preceeding section) to the primate spacecraft, a pertinent question is where should it be added: Alternatives are shown in figure 23. Alternatives indicated by the cross-hatched areas are not applicable since, by definition, docking provisions do not exist for them. Other concepts can be excluded for the following reasons:

(1) This concept does not dock

(2) The coordinate axis for docking the Primate spacecraft intersect at the nominal design center of gravity (at +X = 54.00); hence docking motions for the concepts in column 1 - 7 are inherently along a line through the nominal C.G. Design docking direction not through the CG are excluded by definition. Docking directions which are selected with the velocity vector not passing through the CG can place large shear and moment loads in the structure and thereby lead to significant weight increases. Such conditions should be avoided for the nominal case, especially where the docking mechanism is located with its axis passing through the CG. When the primate spacecraft is attached to the CSM, the combined CG falls on the axis but is outside the primate envelope. In this case, structural loads are imposed by the CSM which is effectively "cantelivered" during side docking, hence impact velocity should be kept significantly lower than the axial docking case for successful side docking alternatives.

(3) Skewed arrangements, where the docking velocity vector is skewed relative to all three orthogonal axes and does not pass through the CG, is not a good design choice due to the asymetry of the loads and the asymetry of the docking direction relative to the tug vehicle's (eg., CSM) body axes. While this alternative, in an absolute sense, may occur as a result of tolerance variations in another arrangement, it is an alternative that should generally be avoided as a nominal design point.

(4) A fixed docking mechanism located in the side in the +X +y or +X -y quadrants will interfere with cage access doors and require significant changes to the design and procedures for loading the primates.

(5) Side located docking mechanisms will exceed the envelope allowables for the Titan and Centaur envelopes unless the docking mechanism is recessed into the primate envelope or retracted during launch. The latter would require a redesign of the cages however.

(6) "On-axis" docking for the y-z plane requires locating the docking collar over the main seal bolt circle ring of the pressure shell when the CG is at Station X = 58.00 or lower. The present CG is at Station 54.00. These alternatives would therefore require significant changes in the present design or the addition of a movable collar.

(7) Location of the docking collar on the +X side of the spacecraft in the +y -z or -y -z quadrants interfere with the cage and recovery capsule geometry and would require extensive redesign.

(8) Added collars to the +X side of the spacecraft would interfere with the present collar for all +X docking.

Nominal design docking direction (i.e., for +x, vehicle moves in the +x direction to dock. ± 45° in plane for cases 9-20, and ± 45° cone for cases 21-28) cg is cg of primate module	Docking mechanism location (fixed docking collar)	1 None	2 +x	3 −x	4 +y	5 −y	6 +z	7 −z	8 Skewed	9 +y, +z quadrant	10 +y, −z quadrant	11 −y, −z quadrant	12 −y, +z quadrant	13 +x, +y quadrant	14 +x, −y quadrant
		Ind. s/c may use tether or furlable boom for coupling to work shop	Use existing docking devices & no tag	Docking equipment added in place of LiOH can	Docking devices added to the side of the primate spacecraft on the z and y axis.				Docking device added at a skewed angle not thru cg						
+x	Thru cg	1	8	8	8	8	8	8	8,3	8	8	8,7	8	8	8
	Not thru cg	1	8,2	8,2	8,2	8,2	8,2	8,2	8,3	8	8,7	8,7	8	8	8
−x	Thru cg								3						
	Not thru cg			2					3						
+y	Thru cg				4,5,6				3,6	5,6	5,6			4,5,6	
	Not thru cg				4,2,5				3,5	4,2	2			4,5	
−y	Thru cg					4,5,6			3,5,6			5,6	5,6		4,5,6
	Not thru cg					4,2			3,5			2,5	5,2		4,5
+z	Thru cg						5,6		3,5,6	5,6			5,6		
	Not thru cg						5,2		3,5	6,2,5			5,2		
−z	Thru cg							5,6	3,5,6		5,6	5,6			
	Not thru cg							5,2	3,5		5,2	5,2			

Candidate concepts

Indicates no docking provisions for docking in this direction

Docking mechanisms for lateral coupling with axial motions are not included due to large side loads and moments: for example a side mounted collar (i.e., the +z side of the s/c) with the docking direction along the x axis

N. A. = Not applicable by definition

Figure 23. - Alternative locations for added docking collar

Nominal design docking direction (i.e., for +x, vehicle moves in the +x direction to dock. ± 45° in plane for cases 9-20, and ± 45° cone for cases 21-28) cg is cg of primate module \ Docking mechanism location (fixed docking collar)		15 −x, −y quadrant	16 −x, +y quadrant	17 +x, +z quadrant	18 +x, −z quadrant	19 −x, −z quadrant	20 −x, +z quadrant	21 +x, +y, +z region	22 +x, +y, −z region	23 +x, −y, −z region	24 +x, −y, +z region	25 −x, +y, +z region	26 −x, +y, −z region	27 −x, −y, −z region	28 −x, −y, +z region
+x	Thru cg	8	8	8	7,8	7,8	8	8	7,8	7,8	8	8	8,7	7,8	8
	Not thru cg	8	8	8	7,8	7,8	8	8	7,8	7,8	8	8	8,7	7,8	8
−x	Thru cg														
	Not thru cg														
+y	Thru cg		5,6					4,5,6	4,5,6			4,5,6	4,5,6		
	Not thru cg		5					4,5	4,5			5	5		
−y	Thru cg	5,6								4,5,6	4,5,6			4,5,6	4,5,6
	Not thru cg	5								4,5	4,5			5	5
+z	Thru cg			5,6			5,6	5,6			5,6	5,6			5,6
	Not thru cg			5			5	5			5	5			5
−z	Thru cg				5,6	5,6			5,6	5,6			5,6	5,6	
	Not thru cg				5	5			5	5			5	5	

Candidate concepts

Indicates no docking provisions for docking in this direction

Docking mechanisms for lateral coupling with axial motions are not included due to large side loads and moments: for example a side mounted collar (i.e., the + z side of the s/c) with the docking direction along the x axis

N.A. = Not applicable by definition

Figure 23. - Alternative locations for added docking collar (concluded)

Examining figure 23, the following are potential locations for the docking collar.

(a) On the lower surface of the spacecraft (-X side) with the -X axiss position preferred.

(b) On the front (+Z) side of the spacecraft in a position above or below the pressure shell bolt circle.

(c) On the sides of the spacecraft, below the bolt circle.

These alternatives are shown in figure 24.

Docked attitude: The docked roll attitude of the CSM, relative to the coordinated axes of the primate spacecraft, is such that EVA effort is minimized for the removal of the animal recovery capsules. This constraint should be maintained for cluster application since it may also be desirable to remove the primates earlier than nominally desired, in case of an abort, for example. Such a constraint suggests that the better locations for any "side" docking alternative as shown in figure 25 would place the added docking collar on the -Z side of the primate spacecraft. Other locations, including the more likely -X surfaces, require some kind of visibility aids since the primate spacecraft would block the astronauts' unaided view of the target. The question of visibility during docking is not unique to the primate module, however, and considerable attention has been given to this subject by both NASA and numerous contractors for the addition of payloads to the cluster. Manual and automatic applicable systems have been studied and subjected to simulation, examples including laser and microwave radars, TV with monitors in the CSM periscopes, and mirror systems. The use of such aids is entirely feasible.

In considering the installation of the primate module on the cluster, two considerations are: (1) which docking port, and (2) what attitude for the primate module. Alternatives are shown in figure 26. The thirty potential alternatives shown here can be reduced to six candidates by the following logic (cross-hatched alternatives are not applicable);

(1) The end docking position will probably be reserved as the CSM main docking and crew access position, and as such is not available to docked payloads.

(2) Radial No. 1 is probably reserved for the ATM.

(3) Radial No. 3 places the primate module in shadow, precluding or restricting the use of self-contained solar-photovoltaic power. The primate experiment draws about 400 watts of steady state power with possible peaks to 1.2 Kw. Since this represents a sizeable load on the workshop's power supply system, it may be particularly desirable to provide the experiment with its own power generating capability.

(4) The use of the +X interface requires a "re-docking" maneuver prior to attaching the module to the cluster. The reason for this is that the CSM docks at the +X interface for primate removal when the spacecraft is operating in the independent mode. The primate capsules recovery are closer to the MDA and some of the hard-line interfaces are already located in this collar; however, the need for re-docking together with the necessity to change either

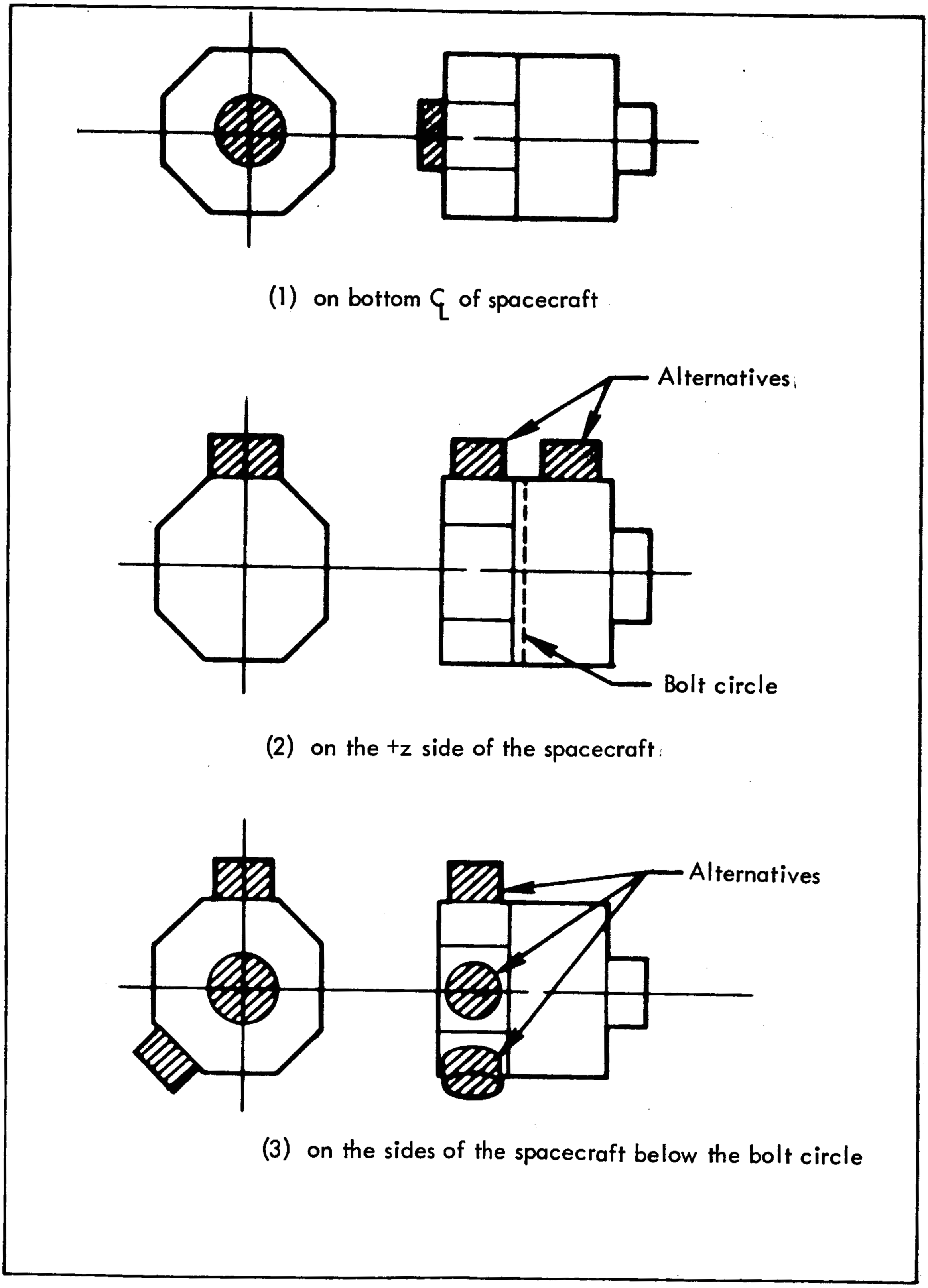

Figure 24. - Docking collar location alternatives

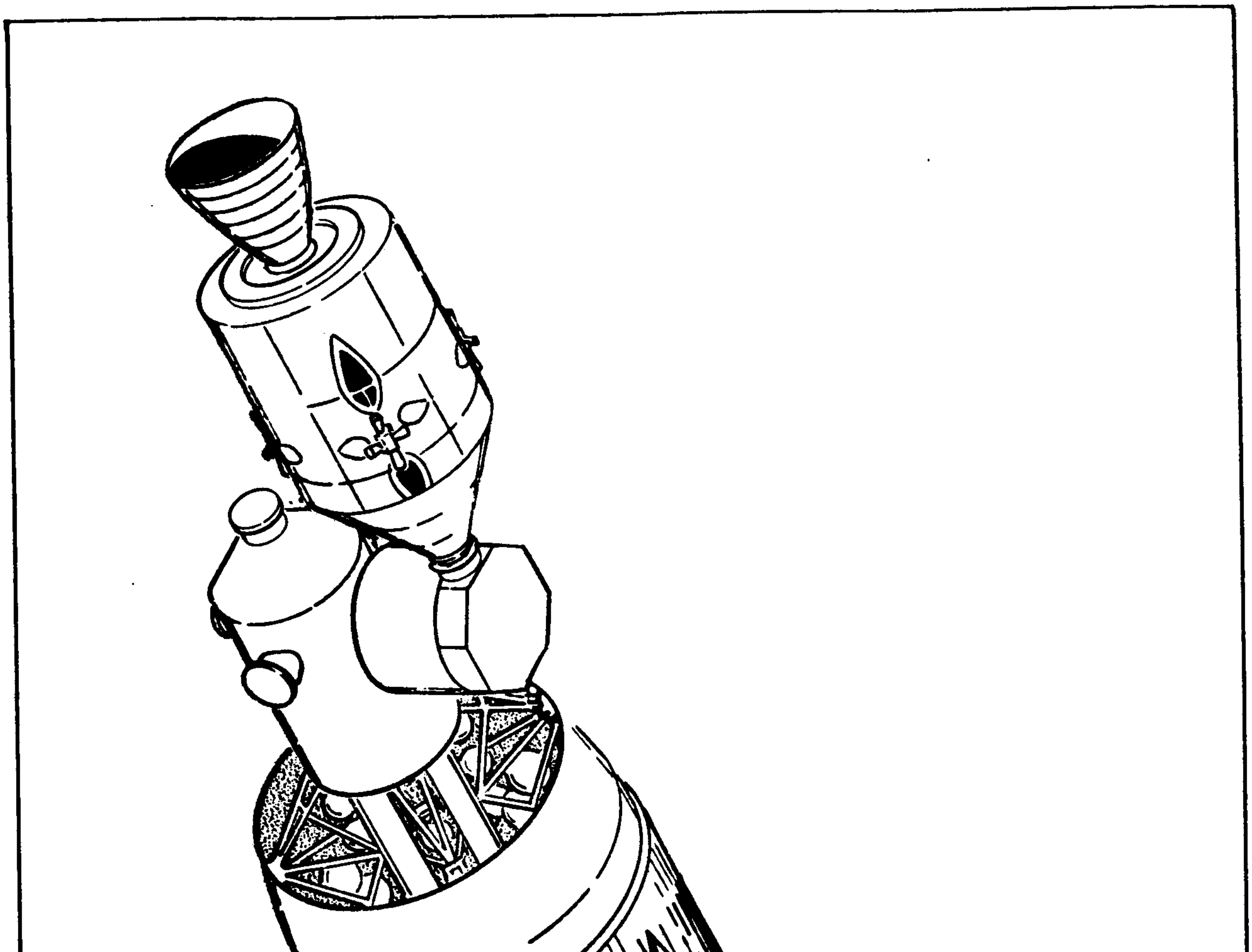

Figure 25. - Radial docking using CSM

Docked attitude \ Docked position	End	Radial #1 (Sun, 1 2 3 4)	Radial #2 (Sun, 1 2 3 4)	Radial #3 (Sun, 1 2 3 4)	Radial #4 (Sun, 1 2 3 4)
+x interface	Eliminate CSM docking primate recovery	Eliminate ATM docking primate recovery	Eliminate primate recovery	Eliminate in shadow primate recovery	Eliminate primate recovery
−x interface	Eliminate CSM docking	Eliminate ATM docking		Eliminate in shadow	
Side dock transverse	N/A	Eliminate ATM docking		Eliminate in shadow	
Side dock longitudinal	N/A	Eliminate ATM docking		Eliminate in shadow	
End dock, transverse, base to sun	Eliminate CSM docking	N/A	N/A	N/A	N/A
End dock transverse, side to sun	Eliminate CSM docking	N/A	N/A	N/A	N/A

Figure 26. - Docked attitude alternatives

the MDA to accommodate a "probe" or to change the drogue to a probe on the primate spacecraft makes this alternative less desirable than direct docking at the -X surface.

Three alternatives therefore appear to be most likely for either of the radial docking interfaces located 90° from the mean sun-line:

(a) Dock to the -X surface of the spacecraft

(b) Side dock with a transverse orientation

(c) Side dock with a longitudinal configuration

Docking maneuver alternatives. - Another question related to docking is the mechanism for effecting the maneuver. Four basic alternatives are as follows:

(1) Manned tug

(2) Unmanned tug

(3) Manned self-contained

(4) Unmanned self-contained.

The manned tug function could be provided by the CSM, by the Gemini spacecraft, or by various space work platforms or space taxies such as those recently studied by Bendix, Bell, Chrysler, and others. Such a tug would take the spacecraft to the cluster and guide it through the docking maneuver.

The unmanned tug functions could be provided by such vehicles as the Bell Dual Maneuvering Unit (DMU) which could be based on the cluster and remotely controlled to "retrieve" the primate module and dock it to the MDA. Present propellant capacity of the DMU would probably have to be increased, however.

The manned-self-contained alternative would provide for "on-board" astronaut control with all motive power being provided by the spacecraft. The primate spacecraft could be equipped with a suitable crew system interface, such as a restraint harness and control position similar to that of the Bell, DMU or the Astronaut Maneuvering Unit.

The fourth alternative, the unmanned-self-contained concept, is one in which the primate spacecraft is capable of performing the entire docking maneuver unaided; except, perhaps, for remote control as illustrated in figure 27. To implement this, additional attitude control and translation capabilities must be provided - larger attitude control thrusters for faster response and additional jets for three axis translation.

All of these alternatives are potential candidates requiring further study.

Resupply and re-use. - Resupply and re-use is an attractive alternative for such experiment hardware as that examined for the primate spacecraft. With the availability of "on-board" maintenance, repair, and modification by the cluster crew, the possibility of refurbishing the module for continued or replacement experiments in a controlled earth-normal (except for gravity and radiation) environment is worthy of careful consideration. An examination of the present spacecraft systems indicate that such re-use is entirely feasible in all but one area: waste management. Expendables tankage (O_2, N_2, & water) can be readily refilled by either an EVA, or IVA, or by routing the plumbing to the docking collar at the MDA interface. Equipment modules, batteries, LiOH canister and other such items can be removed and replaced by EVA through the existing access panels and doors. Waste, however, is a particular problem; the present system has no provisions for astronaut cleaning or replacing of the waste collection and treatment equipment in orbit.

Addition of this capability would require either a redesign of the unit or a design point of a longer duration. For example, the waste collection screens could be designed for two or three years of operation if the presence of older material did not degrade the experiment data of more recent tests. Such an approach would require significantly larger screens however, since their capacity varies directly with the area of the screen. As an alternative the screens could be designed as removable, throwing away, items and be replaced in space by new units brought up by the logistic vehicles or carried in the workshop.

Candidate orbital laboratory configuration. - One of the more attractive alternatives for adding the primate experiment to the orbital workshop is illustrated in figure 28. The LiOH canister has been replaced with a docking

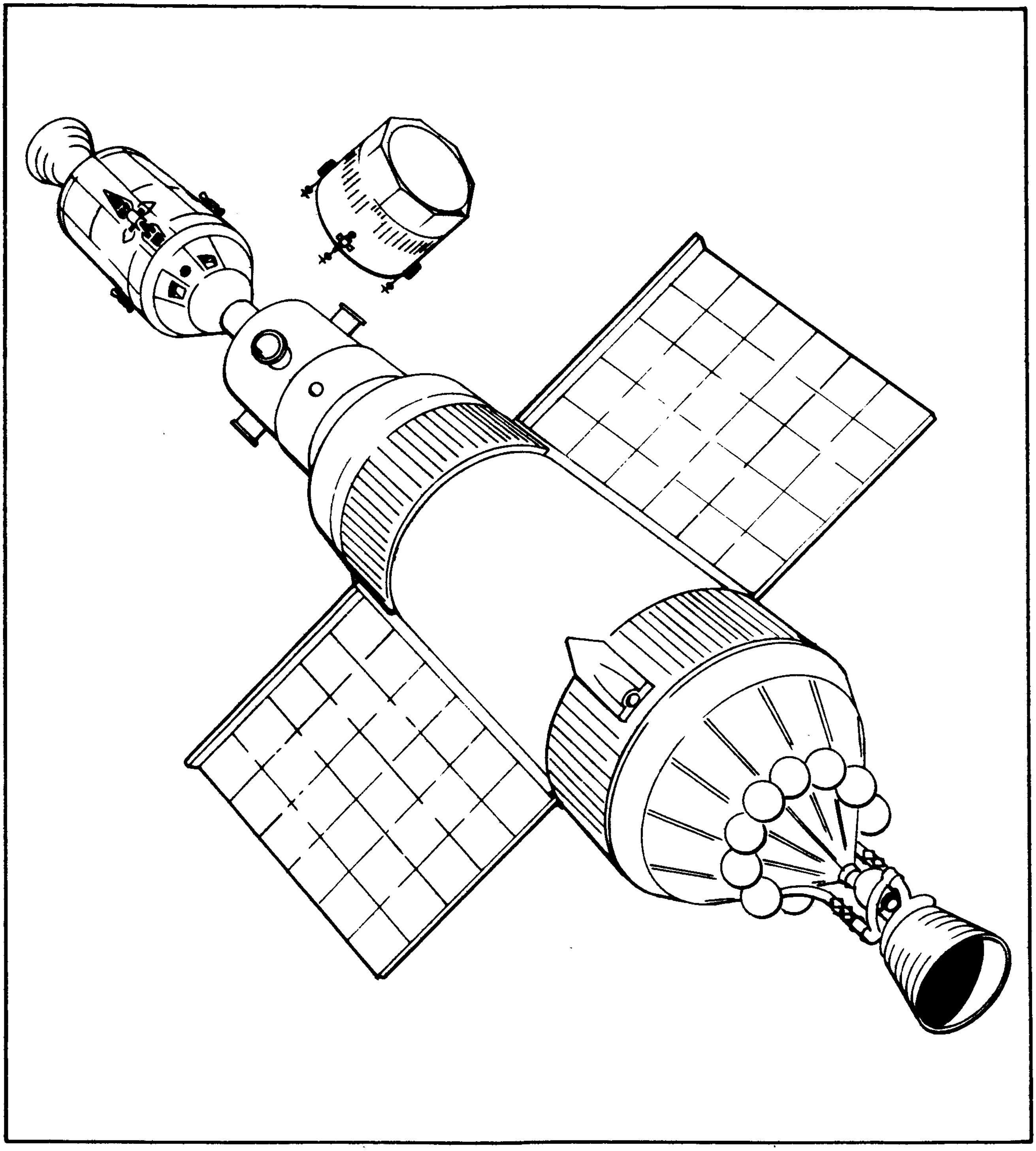

Figure 27. - Remote control docking by OPS

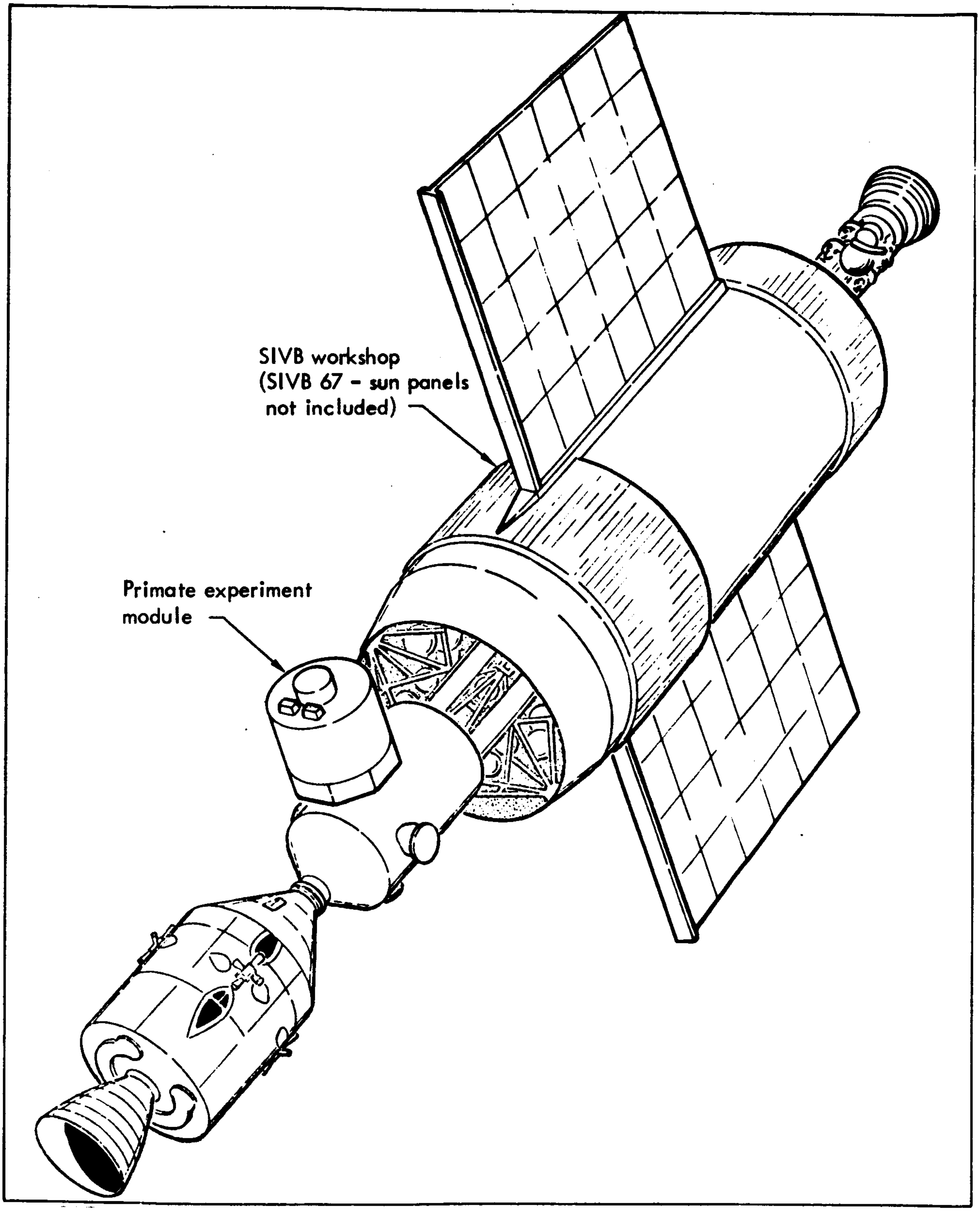

Figure 28. - Orbital workshop with primate module attached (cluster A less all payloads except primate module)

mechanism and the module attached to the MDA at one of the radial docking ports located 90° from the sun line. This alternative requires changes to the existing design as follows:

(1) Life support and environmental control: Relocate existing LiOH canister and replace with two units located in the unpressurized bays. The units will probably require the addition of a heater.

(2) Structure and mechanical: Strengthen the cylindrical structure previously located around the LiOH can by increasing the material gage from the present .04 to about .09 and add stiffeners as required. Replace the machined ring previously supporting the LiOH can with one configured to the requirements of the docking probe and latches. Delete the present solar panels and associated mechanism. Move antenna deployment mechanisms to the y - z plane.

(3) Instrumentation Subsystem: Add interface for hardline to workshop data system, and relocate antennas.

(4) Command and Control: Add hardline to workshop.

(5) Electric Power and Cabling: Increase battery capacity to power experiment until docked to the workshop. Add hardline connection to workshop power substation in the MDA.

(6) Attitude control: Off load tankage as required.

In addition to these modifications and changes the following should be considered:

(1) The primates can be directly observed by crew in the MDA. To facilitate this, several alternatives are possible. For example, a periscope can be housed in a pressure tight tube which extends "upward" from the lower bulkhead between the cages to a position where the periscope head can see directly into the cages through a transparent section of the sleeve. After the primate module is docked and the probe and drogue removed, the periscope can be extended into the MDA for direct observation or photography by the crew. When the periscope is not used, it can be "retracted" into its housing and the docking port hatch closed to maintain the pressure integrity of the MDA. Other techniques using mirrors, light-pipes, closed circuit TV, etc. can also be considered.

(2) All hard line interfaces can be completed in a short sleeve environment by locating the connections in the docking collar. In addition, fill and drain lines can be located here for refurbishment direct from the MDA interior or to provide the crew with emergency access to the stored gasses and water as a backup contingency system.

(3) The primate module can probably be equipped with solar panels which face the sun "between" the panels of the ATM. This was of doubtful possibility

with early ATM solar panel configurations; however, the "windmill" configuration shown on more recent orbital workshop concepts should be compatible with this. The Primate solar array for this application will, of course, be different from that presently shown.

(4) Antenna configurations are to be determined such that the primate S/C does not interfere with workshop's patterns.

(5) Regarding safety, the primate module will not impose any serious threat to the workshop interior from leakage into the MDA. This can be confidently stated since it is entirely feasible to vent the docking collar to space with the MDA hatch sealed. When the hatch is opened, the risk is still satisfactorily small since the pressure shell fitting penetrations into the lower bulkhead can be confined to the space outside of the docking collar; a periscope (or similar penetration) can be housed in a sealed sleeve which can vent to space through a burst diaphram should a potentially hazardous leak develop. Further, the module can be pyrotechnically separated from the cluster by attaching the docking collar latch ring to the module with a V-Band clamp as described in Volume III.

(6) The primate module will also require additional thermal insulation due to the close proximity of the MDA thermal radiator.

Example mission operation. - In this example, the orbital workshop is launched as the second of four Apollo Applications flights and uses the Uprated Saturn I launch vehicle.

The first flight (AAP-1) of the example mission is the launch of a manned spacecraft and the primate experiment into a 100 n. mile circular parking orbit where the primate experiment is prepared for installation on the workshop.

AAP-2, which includes the spent SIVB stage, an Airlock Module, and a Multiple Docking Adapter, will then be directly injected into a 260 n. mile circular orbit. After achieving orbit, the SIVB residual propellants will be dumped and the attitude of the vehicle will be stabilized.

Flight of the first payload in the 100 n. mile orbit and the second one in the 260 n. mile orbit will continue for orbital phasing. When proper phasing has been achieved, the AAP-1 service propulsion system will be fired to initiate a rendezvous, figure 29, with the spent SIVB stage at 260 n. miles.

The primate experiment will then be docked to the multiple docking adapter (MDA) and the CSM subsequently separated from the primate experiment and also docked to the multiple docking adapter (MDA) as illustrated in figure 30. Crew members will then move to the airlock module to begin preparing the orbital workshop for occupancy and experiment operation. Normal operation, including rest and duty cycles, will be conducted for the remainder of the open ended mission of up to 28 days. On the last day

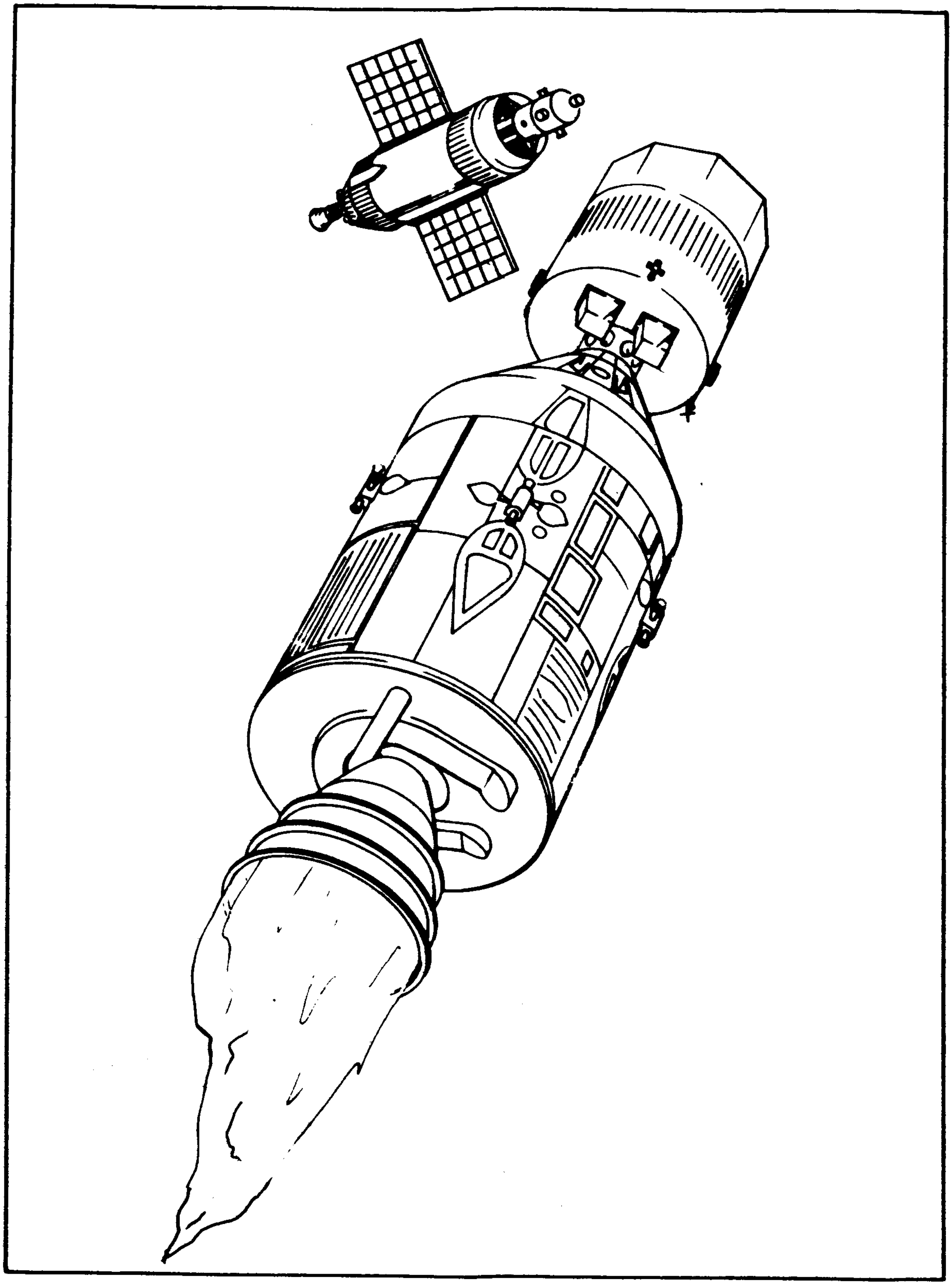

Figure 29. - OPS transfer by CSM

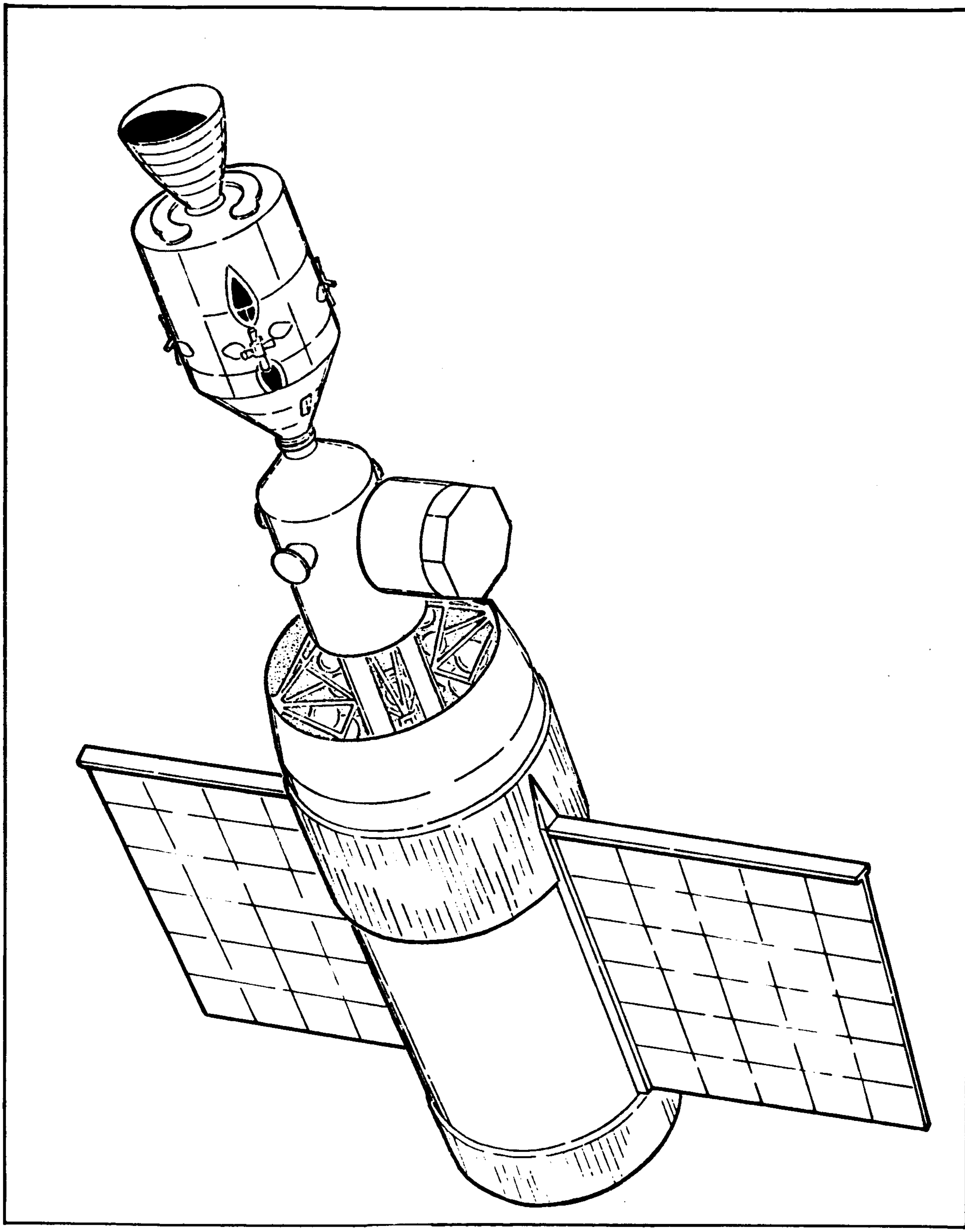

Figure 30. - Completed docking

the SIVB workshop, multiple docking adapter and the airlock will be prepared for in-orbit storage and the primate experiment prepared for unattended operation. After completing this task, the Apollo spacecraft will undock from the cluster and the crew will return to earth to complete the first phase of the cluster mission.

From three to six months after AAP-1 spacecraft returns, the cluster mission will be continued with the launch of the third uprated Saturn I. The payload, consisting of a manned Apollo CSM, with extra expendables, would be inserted into a low altitude parking orbit. Approximately one day later, the AAP-4 payload carrying a lunar module ascent stage and the Apollo Telescope Mount and experiments, would be launched and directly injected into a circular orbit approximately 20 miles below and coplanar with the orbiting workshop. The Apollo CSM would rendezvous and dock with the Lunar Module/Apollo Telescope Mount and detach the LM/ATM from the launch vehicle. The CSM propulsion system would then be used to perform the terminal phase maneuvers for rendezvous with the still-orbiting workshop. Upon rendezvous, crewmen will transfer to the lunar module to activate it, undock from the CSM and proceed to dock to the workshop.

Crew activities and experiment operations would be performed for up to 56-days and approximately two days prior to the last day, the workshop, the lunar module, and the Apollo Telescope Mount would be prepared for in-orbit storage and the primate experiment again prepared for unattended operation. On the last day, orbital flight will be continued until the position of AAP-3 spacecraft is appropriate for re-entry. The spacecraft propulsion system will be fired to provide the required retro impulse. The command module (CM) will be separated from the service module (SM), stabilized for re-entry and recovered.

About one year after the launch of AAP-1, a fifth AAP launch, consisting of an Apollo CSM and additional experiments and expendables, will re-man the workshop. Prior to return, this crew will recover the primates together with specimens and data for return to the earth.

Modular OPS external and internal to workshop. - In addition to docking the complete OPS to the MDA, (figure 31A) the primate experiment could be packaged in modular form and mounted before launch around the workshop airlock and internal to the workshop itself. Figure 31 B shows this concept. The main life cell structure is secured to the external skin of the airlock and the support equipment (electronics, plumbing and air fans, heat exchangers, etc.) are grouped in close proximity to the life cells. Atmosphere gases (O_2 & N_2) are stored in pressure bottles inside the SIVB hydrogen tank. This concept dictates that while the experiment is launched with expendibles on board, the primates will be installed after the workshop is placed in earth orbit and the system checked out for proper operation.

Modular OPS external to workshop. - If in addition to the basic life cells all of the experiment support equipment is located external to the workshop module, the primates may be installed before launch. This concept is shown in figure 31 C. Installing the primates before launch simplifies

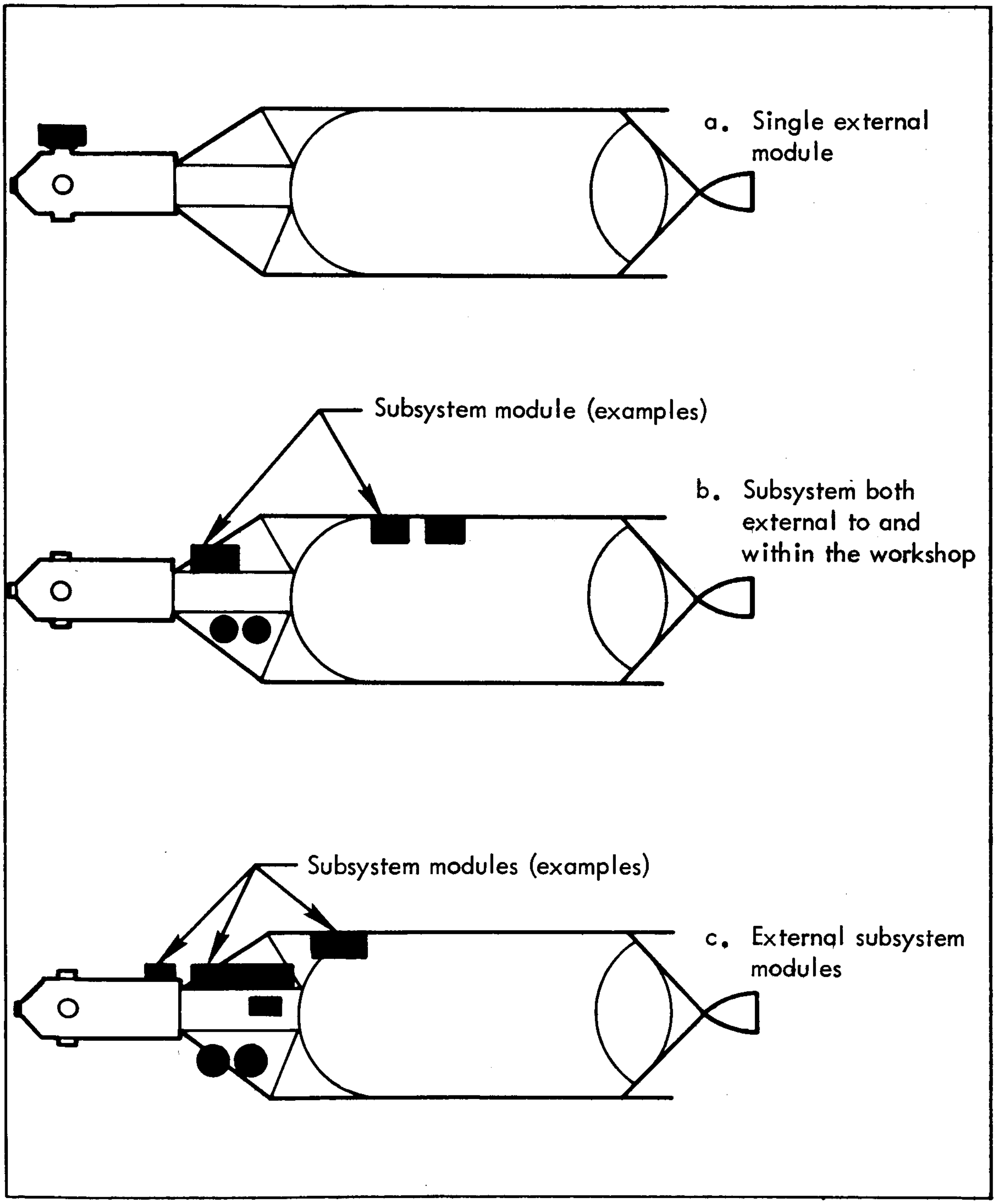

Figure 31. - Alternative installation approaches

the placing of the modules and does not require astronaut participation to activate the experiment. On the other hand, a launch and orbit insertion with a non-functioning experiment (no primates on board) precludes possible primate injury during an unrestrained launch. This concept would require that the primates be brought up into orbit in a CSM resupply vehicle and inserted into the life cages through parts in the airlock wall. The primates could be launched in recovery type capsules containing their own atmospheres so that astronauts will not come in direct contact with the animals or their atmospheres.

In either concept, B or C shown on figure 31, once the experiment has been started, no further astronaut activity will be required. However, astronaut monitoring of both the primates through parts in the airlock wall and experiment subsystem is entirely feasible. The experiment will only require electric power from the workshop and communication tie into the STUB telemeter system if the OPS communication system is not installed.

Of all the concepts outlined above, subsystem modules mounted external to the workshop with the primates installed before launch appears to offer the least complication and is the preferred method.

Utilization of OPS subsystems in SIVB workshop. - The Orbiting Primate Spacecraft's Life Support Subsystem as presently designed consists of a group of subassemblies capable of supporting two 13 pound primates for periods of up to one year in the space environment. With electric power supplied and waste heat removed from the various components, this system will function independently for up to one year to provide a controlled atmosphere, food, and water to the experimental animals. The OPS Life Support Subsystem is ideally suited for installation as a self-contained, independently operating entity inside the Saturn SIVB Workshop.

As now designed, the SIVB tankage carries a minimum of modification to enable its use as a manned workshop after placing itself in orbit. These modifications consist of:

1. A larger entrance hatch in the domed end.

2. Bracketry welded on the interior tank walls.

The enlarged entrance hatch will accommodate any bulky material that will be placed inside the stage after the propellant is exhausted, and the bracketry will be used to secure this hardware once it is inside. At present, it is planned to partition the empty stage into a laboratory area and a crew living area. After the construction work is completed, an airlock module (AM) and multiple docking adapter (MDA) will be maneuvered into place over the hatch and the entire assembly pressurized with a life supporting atmosphere.

During operation of the workshop, a three-man crew using an Apollo CSM will dock with the orbiting stage, pass through the airlock and spend time performing tasks inside the spent hydrogen tank. It is expected that the orbital life time of the workshop will be one year or more depending on the number of resupply missions, meteoroid damage, etc. However, it is not expected that any one man will spend any where near a full year in the laboratory during its first year in orbit. In all probability, several CSM resupply missions will be flown during the first year with an astronaut spending from two weeks to several months in the workshop and then returning to earth as a crew member of the next CSM resupply vehicle.

Immediately after SIVB workshop assembly and commission, a complete OPS Life Support Subsystem could be transported to orbital altitude, passed through the airlock and installed inside the workshop pressure shell. The components of the subsystem would be modularized into sizes compatible with the 40" diameter of the airlock and hatch during the trip from the earth. Assembly and checkout would take place inside the workshop under shirtsleeve conditions with the assembled unit being fastened to brackets already installed in the pressure shell on earth.

Only two basic modifications to the OPS Life Support Subsystem would be required. First, a light biological barrier would be installed around the subsystem (including animal cages) so that complete separation of primate atmosphere and workshop atmosphere would be assured. And second, essential service connections (electric power, communications links to either SIVB antennas or SIVB telemetry and vacuum vents) would be required. In the case of communication, either the complete OPS command and telemetry subsystem could be used and simply tied into the SIVB antennas or the OPS sensors could be tied directly into the SIVB communications system.

During operation when the OPS Life Support Subsystem is being used to support either primates or other animals, the unit would be completely self sustaining as long as electric power was supplied. If an animal change was required during a test, a simple device similar to the OPS recovery capsule could be used to make the transfer without contaminating the workshop atmosphere.

The ability to monitor and make inflight adjustments and changes to the experiment offers a strong incentive for integration into the SIVB workshop.

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